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Final Report

EVALUATION OF EMISSION CONTROL STRATEGIES FOR AIRFIELD OPERATIONS AT THE LOS ANGELES AND SAN FRANCISCO INTERNATIONAL AIRPORTS

Prepared for

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ABSTRACT

This report reviews potential air pollutant emission reductions which could be achieved by various strategies to control airfield operations at Los Angeles and San Francisco International Airports, and examines safety problems, cost impacts, potential fuel savings, time frame for strategy implementation, and potential regulatory and jurisdictional conflicts associated with each strategy.

Airfield emission sources studied included aircraft operations in the idle, taxi, takeoff, and landing modes; ground service vehicles; fuel handling and storage; and aircraft engine maintenance. Nineteen potential strategies were identified, and seven strategies were selected for detailed analysis and examination after a preliminary evaluation.

Two strategies, aircraft towing and reducing the number of operating engines on the ground, appear to provide the most significant emission reduction. Both of these strategies offer potential reductions in the range of 20 to 40% of the carbon monoxide and hydrocarbons which are currently emitted by ground operations. The aircraft towing strategy also offers a comparable improvement in suspended particulate matter emissions.

When the overall feasibility of each strategy is evaluated, the strategy to reduce the number of operating engines appears to be the most viable since its implementation would result in fuel savings, no apparent safety problems, and it can be implemented immediately.

This report was submitted in fulfillment of Agreement # A7-077-30 by AeroVironment Inc., under the sponsorship of the California Air Resources Board. Work was completed as of August 1978.

ACKNOWLEDGEMENT

This report was prepared for the California Air Resources Board, Research Division, as part of its broad research program to resolve fundamental technological problems related to the design of effective, economically viable, and socially acceptable strategies to achieve cleaner air. This report represents the joint efforts of a project team consisting of AeroVironment Inc. (AV), in association with Peat, Marwick, Mitchell & Company (PMM).

AeroVironment was the prime contractor with responsibilities in the following areas: overall technical direction and project management; description of aircraft ground operation strategies; emission and fuel consumption estimates; strategy analysis and impact evaluation; and final report preparation. Peat, Marwick, Mitchell & Company was a subcontractor to AV with responsibilities in the following areas: aircraft operational data, including traffic mix, distribution, and flow patterns; aircraft taxi and idle times; description of aircraft ground operation strategies; and strategy analysis and impact evaluation.

The author and project manager of this study was Mr. C. Gary Gelinas of AeroVironment Inc. Dr. Henry Fan of Peat, Marwick, Mitchell & Company provided technical advice during the project and served as coordinator in the performance of PMM's subcontract with AV. Dr. Steve Hockaday of PMM also provided technical advice during the initial stages of the project. Mr. Robert Baxter of AV contributed to the project by performing many of the data computations. The author appreciates these contributions.

TABLE OF CONTENTS

LIST OF TABLES

1. SUMMARY

This study determined potential emission reductions which could be achieved by various strategies to control airfield operations at Los Angeles and San Francisco International Airports. Also, this study examined safety problems, cost impacts, potential fuel savings, time frame for strategy implementation, and potential regulatory and jurisdictional conflicts associated with each strategy.

In order to determine emission reductions and fuel savings which might result from implementing a given strategy, a baseline inventory was prepared for both pollutant emissions and fuel use. This baseline inventory represented the "without" strategy case and was compared to the results of each "with" strategy case. This comparison was used to determine the percent savings which could be achieved.

The baseline emission inventory was prepared for four pollutants: carbon monoxide (CO); total hydrocarbons (HC); oxide of nitrogen (NO_x); and total suspended particulates (TSP). Airfield emission sources included: aircraft operations in the idle, taxi, takeoff, and landing mode; ground service vehicles; fuel handling and storage; and aircraft engine maintenance. For CO and HC, taxi and idle of aircraft accounted for more than 70 percent of the airfield emissions. For NO_x, takeoff of aircraft accounted for more than 75 percent of the airfield emissions. For TSP, the total airfield emissions were only 1 percent of the total CO emissions.

Nineteen (19) potential strategies were identified that could reduce total airfield emissions. A preliminary evaluation of these potential strategies was performed to screen out those which may not be viable. This preliminary evaluation was based on qualitative estimates of strategy effects on airfield operations. Seven (7) strategies were selected for further analysis and examination as a result of the screening process. These strategies are as follows:

- Aircraft towing
- Reduce number of operating aircraft engines
- Passenger load increase
- Strengthen Sepulveda Tunnel
- Control departure times
- Alternative deceleration pattern
- Runway assignment

The results of the quantitative analysis of the seven selected strategies appear to indicate that aircraft towing and reducing the number of engines would provide the most significant reduction in airfield emissions (in the range of 20 to 40%) for CO and HC. The towing strategy also offers significant reduction in TSP emissions (15 to 25%), while the option of reducing engines increases the TSP emissions (5 to 20%). At Los Angeles, the combination of two strategies, runway assignment and strengthening Sepulveda Tunnel, would provide a reduction of 10 to 15% for CO, HC, and suspended particulate matter. None of these strategies seem to reduce NO_x emissions significantly (less than 5%).

Two strategies, passenger load increase and control departure time, did not appear to reduce emissions of any pollutant more than 10%. The alternative deceleration pattern strategy provided a substantial reduction in NO_x emissions (10 to 15%); however, this strategy would increase CO and HC emissions at the same time by 10 to 15%.

The strategies that appear to provide the largest fuel savings were aircraft towing and the combination of runway assignment and strengthening Sepulveda Tunnel at Los Angeles. Two of the strategies analyzed, aircraft towing and alternative deceleration pattern, could have potential safety problems.

The results of this study indicated that one strategy, to reduce the number of aircraft operating engines, would appear to be most viable, when considering emission reductions, costs, time requirements, and safety aspects. Since the estimation of the cost impact of aircraft towing could not be determined within the scope of this study, the analysis of this strategy was not completed and, therefore, this strategy could also be a viable candidate. However, the viability of this strategy would depend upon determination of a beneficial cost impact and resolution of the safety issues.

2. INTRODUCTION

The reduction of air pollutant emissions from major airports has been an area of concern for most governmental agencies responsible for air pollution control in California. When Congress passsed the Clean Air Act Amendments in 1970, they intended that the U.S. Environmental Protection Agency (EPA) would regulate the aircraft engine manufacturers in meeting federal emission standards and that State and local agencies were pre-empted from establishing any standards which were different than standards adopted by the EPA. This was done to avoid conflicting requirements between airports in different States which might cause problems due to the interstate nature of air travel.

Recently, the State of California, Air Resources Board (ARB) decided to study other available options for further reducing airport emissions in areas where the ARB, or a local air pollution control agency, may have jurisdiction. Therefore, this study was initiated to determine potential emission reductions which could be achieved by various strategies to control airfield operations and to examine impacts associated with these strategies. Two major airports in California, the Los Angeles International Airport (LAX) and San Francisco International Airport (SFO), were selected as case study airports. However, other airports may also be considered by the ARB at a later time.

The scope of this study includes the following:

- Preparation of a description of the airfield operations.
- Preparation of a baseline airfield emissions inventory.
- Identification of potential strategies for reducing emissions.
- Performance of a preliminary evaluation of potential strategies to screen out those which may not be viable.

- Analysis and examination of those strategies which appear to be viable.

- Preparation of conclusions on the results of the analysis and examination.

Two categories of airfield emission sources (which comprise the airfield ground operations) were considered in this study. They are as follows:

- Aircraft operations.

- Ground equipment operations.

Aircraft operations include commercial passenger, commercial cargo, and general aviation aircraft. The types of operational modes include: departure - idle, taxi, takeoff; arrival - idle, taxi, landing. Takeoff and landing modes were considered only during the time the aircraft was on the active runway and does not include the time spent in climb-out or approach. Also, the operations of auxiliary power units (small on-board gas turbine engines) which provide power while the main engines are not in operation were considered as an emission source.

The ground equipment operations include: ground service vehicles; fuel handling and storage; and aircraft engine maintenance. The operation of these emission sources was determined to be directly related to the number of aircraft operations.

Motor vehicle emissions from access traffic (vehicles entering or leaving the terminal area) were not considered in this study since they are not involved with the operations on the airfield.

The types of associated impacts which were examined in this study are as follows:

- Safety
- Costs
- Fuel savings
- Time frame required for implementation
- Regulatory and jurisdictional conflicts

This report is organized according to the following outline: Chapter 3 describes both the aircraft and ground equipment operations at LAX and SFO; Chapter 4 presents baseline (before strategy implementation) aircraft operational data, fuel consumption, and emissions; Chapter 5 discusses the strategies identified and results of a preliminary evaluation and screening; Chapter 6 presents an analysis and examination of the strategies selected for further evaluation; and Chapter 7 summarizes the results of the study and presents conclusions.

3. DESCRIPTION OF AIRFIELD OPERATIONS

Both aircraft and ground equipment operations at Los Angeles International Airport and San Francisco International Airport are described in this chapter.

3.1 Aircraft Operations at LAX

The layout of Los Angeles International Airport is shown in Figure 3-1. The airport has two pairs of parallel runways: the north runways (6R-24L and 6L-24R) and the south runways (7R-25L and 7L-25R). Aircraft operations on the south runways are generally independent of operations on the north runways. Each pair of runways has its own air traffic controllers.

The predominant runway use is to land and depart to the west, i.e., on Runways 24L, 24R, 25L, and 25R. Prevailing winds permit this runway use about 98% of the year.

Use of the airport is constrained by the limited loadbearing capacity of some runways and taxiways. Wide-body aircraft are prohibited from using Runway 25R. Also, wide-body aircraft weighing more than 325,000 pounds are prohibited from using Runway 25L and those taxiways which cross the Sepulveda Boulevard tunnel. Noise abatement restrictions prohibit the use of Runway 24R by departing aircraft weighing more than 12,500 pounds. This latter restriction may be waived by the tower supervisor if significant delays are encountered or if there are runway closures elsewhere on the airport. Preferential runway priorities for noise abatement purposes are: 25R, 25L, 24L, and 24R.

As a result of these constraints, narrow-body aircraft normally land on the south runways, and wide-body aircraft normally land on the north runways (or on 25L, providing they meet the weight criteria).

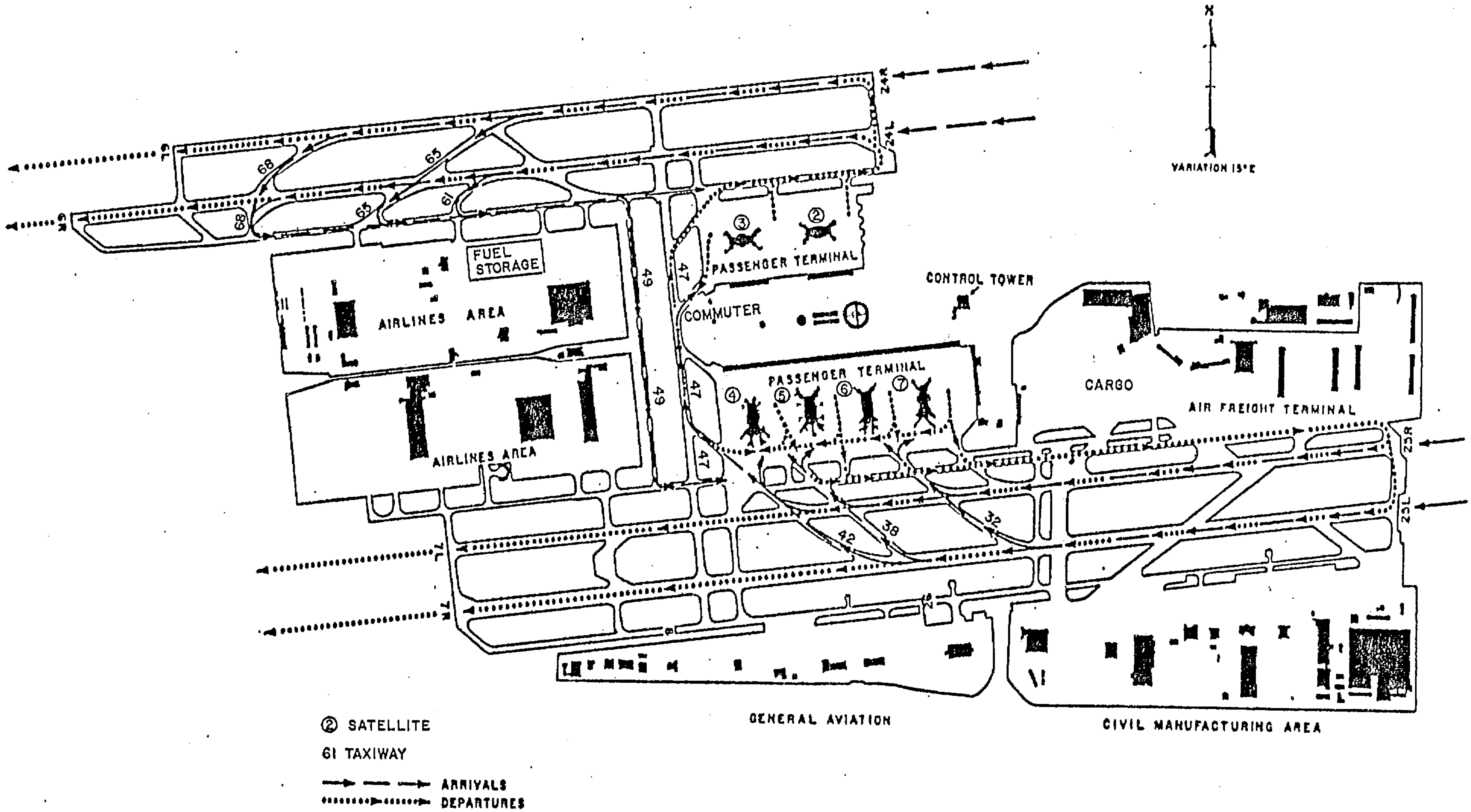

FIGURE 3-1. Runways, taxiways, and terminals at LAX.

Runway assignments for departures normally reflect the route of flight after takeoff. Northeast and northbound flights normally use the north runways; west, southwest, and southbound flights normally use the south runways. Heavy aircraft normally use the north runways for departures regardless of direction of flight.

The taxi routes followed by arriving aircraft to the gates depend on the arrival runway. Aircraft arriving on Runway 25L or 25R destined for gates on the south side of the terminal complex use Taxiways 32, 38, and 42. Aircraft arriving on Runways 25L and 25R destined for gates on the north side of the terminal complex use Taxiways 42 and 47. Aircraft arriving on Runways 24L or 24R exit the runways at Taxiways 61, 65, or 68, then taxi east on the parallel taxiway to gates on the north side of the terminal complex or proceed via Taxiways 47 or 49 to the south side of the terminal complex.

The taxi routes followed by departing aircraft depend on the location of the departure gate. Aircraft taxiing from the south side of the terminal complex to Runway 25L or 25R make a left turn on the outer taxiway and proceed to the runup area. Aircraft departing on Runways 24L or 24R normally make right turns on the ramp (inner taxiway), then proceed north on Taxiway 47 to the parallel taxiway, and then to the runup area. Aircraft proceeding from the north complex to Runway 25L or 25R reverse the procedure, traffic permitting. If Taxiway 47 is occupied, the aircraft taxi south on Taxiway 49. Aircraft departing from the north side of the terminal complex for Runways 24L or 24R proceed from the nearest ramp exit to the runway.

3.2 Aircraft Operations at SFO

The San Francisco International Airport, shown in Figure 3-2, has two pairs of closely spaced parallel runways which intersect at right angles directly in front of the control tower. Runways 28L, 28R, and 19L have full Instrument Landing Systems (ILS); runway 10R has an approved back course approach.

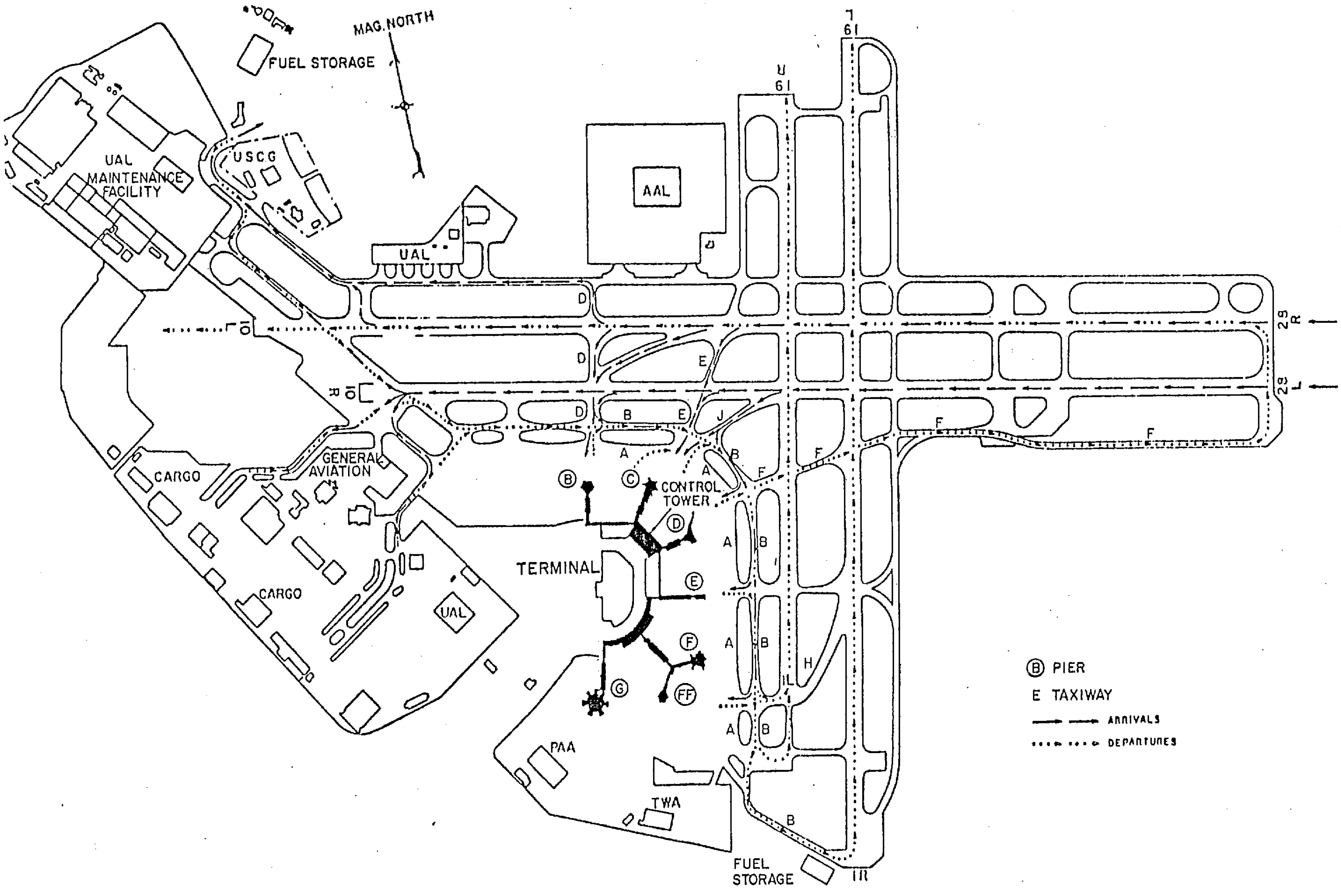

FIGURE 3-2. Runways, taxiways, and terminals at SFO.

There are no operating constraints regarding aircraft size or weight on any runways or taxiways. The inner taxiway A is rarely used except for short distances because it is frequently blocked by aircraft pushing back from the outermost concourse gates.

One air traffic controller controls all aircraft taxiing on the airport. Aircraft departing from their gates notify the controller before starting push-back, and the controller approves the push-back, depending on other taxiing traffic. The mix of arrivals and departures using the outer taxiway B requires careful and extensive preplanning on the part of the ground controller to ensure a smooth flow of traffic.

The predominant "West Flow" configuration is used about 92% of the time. Most of the time, arriving aircraft use Runways 28 L/R and departing aircraft use Runways 1 L/R. Wind conditions allow this configuration about 67% of the time. The remainder of the time, aircraft both arrive and depart on Runways 28 L/R. Arriving aircraft contact the air traffic control tower when they are approximately six miles from the runway. Initially, the approach controller in terminal area radar control (TRACON) assigns the landing runway; however, the tower controller may, after coordination with TRACON, change the assigned runway.

For departing aircraft, the general rule used to determine the departure runway is to assign aircraft that must make a left turn after takeoff to use Runway 1L, and aircraft that must make a right turn after takeoff to use Runway 1R. An exception to this rule is that most heavy jets use Runway 1R to take advantage of the extra runway length.

Aircraft ground movement patterns for this configuration are also shown in Figure 3-2. Aircraft arriving on Runway 28L exit at Taxiways J, E, or D and then proceed via the outer taxiway to their gate. Air traffic control clearance must be obtained before crossing Runway 28L. Aircraft arriving on Runways 28L and 28R that are bound for the cargo terminals exit at the ends of the runways and proceed via Taxiways S or R.

Aircraft departing on Runway 1L taxi via the outer taxiway and wait for takeoff on either Taxiway H or on the runup area at the south end of the runway. Aircraft departing on Runway 1R remain on Taxiway B. Aircraft departing on Runway 28R use Taxiway F to the end of the runway. Clearance must be obtained from air traffic control before crossing Runways 1L, 1R, and 28L.

3.3 Ground Equipment Operations

The types of ground equipment operations considered in this study were: ground service vehicles; fuel handling and storage; and aircraft engine maintenance.

Ground service vehicles are used to provide a variety of routine functions during periods when aircraft are not in flight. The same general types of vehicles are located at both LAX and SFO. Description of the functions of each vehicle type are as follows:

- Light Duty Tractor - towing luggage carts and containers to and from the aircraft and terminal building.
- Belt Loader - loading and unloading luggage and packages.
- Container Loader - loading and unloading specialized containers and large items.
- Cabin Service - routine changing of printed materials and clean-up of the aircraft interior.
- Lavatory Truck - maintenance and disposal of sanitary facilities.
- Water truck - replenishing the fresh water supply.
- Food Service - provides catering service.

- Fuel Truck - supplies the pumping service to transfer fuel from the underground fueling hydrants to the aircraft; or supplies fuel to the aircraft directly from a tank on the truck.

- Tow Tractor - towing aircraft to and from gates and to and from maintenance facilities.

- Air Conditioner - provides cooling to the aircraft cabin when the aircraft does not have a self-contained power unit (done only during warm weather).

- Air Start - used in starting aircraft by supplying high pressure air to each engine.

- Ground Power Unit - supplies electrical power to aircraft without an auxiliary power unit while at the gate.

These types of vehicles are the most frequently used. However, there are other special purpose vehicles which are used on occasion but are not included in this study. Most of the ground service vehicles are owned and operated by the airlines, but in some cases several service organizations supply rental equipment to the airlines.

At LAX fuel is transferred from the bulk storage area to the day storage area where it is then allocated to hydrants at the six terminal satellites. All pumps along the underground system are equipped with mechanical seals to prevent hydrocarbon losses and are automatically controlled to provide a continuous suppply of fuel to the terminal satellites. All hydrants are below grade, have tight-fitting metal covers, and are closed with quick coupling valves. Vapor recovery systems are used throughout the fuel storage system to help minimize hydrocarbon losses.

Jet aircraft, for the most part, are fueled from the hydrants by means of "go trucks" equipped with flexible, quick coupling line sections, meters, and filters. A number of commercial and general aviation aircraft are fueled by large tank trucks which are filled at various storage facilities and driven to the aircraft. Fueling by tank trucks accounts for a small fraction of the total fuel transferred to aircraft.

At SFO there are three major fuel storage facilites. Their locations are at the north end near the U.S. Coast Guard, south of the terminal near runways 1 L/R, and along the old Bayshore highway. More than 90 percent of the aviation fuel handled by these facilities is kerosene. Fueling of aircraft is handled by two methods: hydrants and large tank trucks. About 50 percent of the gates have hydrants, while aircraft parked at the remaining number of gates are be serviced by the tank trucks.

Gas turbine engines are tested and maintained at both LAX and SFO. A major maintenance facility at SFO, which is operated by United Airlines, is the largest of such facilities at the two airports. Engines are stabilized at various power settings for periods of time sufficient to check for oil leaks and malfunctions. These tests are primarily done while the engines are intact on the aircraft. However, some engines are removed and mounted on a special test stand for repair and testing.

4. BASELINE AIRFIELD FUEL USE AND EMISSIONS

This chapter presents aircraft and ground equipment operational data, estimated baseline airfield fuel use and emissions, and the methodology used in preparing the estimates.

4.1 Aircraft Operational Data

Aircraft operational data were developed for an average day of the year for both LAX and SFO. These data included the number of operations by aircraft type and by hour of the average day. Table 4-1 shows the distribution of operations by aircraft type for the average day. Figure 4-1 presents the distribution of operations by hour of the day. The data indicate that B-727's account for the majority of the operations and that 9 AM to 9 PM is the most active period at both airports. Military aircraft operations were determined to be negligible and were not considered in this study.

The total number of operations for the average versus peak day are as follows (note August is the peak month):

	Number of Operations	
Time period	LAX	SFO
Average day of year	1,445	924
Average day, peak month	1,764	1,012
Peak day, peak month	1,961	1,127

Data on aircraft operations were obtained from the Federal Aviation Administration (1978) air traffic control tower records at LAX and SFO. Aircraft mix data were derived from information in the Official Airline Guide (Reuben H. Donnelley Corporation, 1977-1978) and FAA air traffic control tower records.

Data on taxi times were developed for a typical aircraft arriving and departing during an average day between terminal areas and runways. In

TABLE 4-1. Distribution by aircraft type of average day operations at LAX and SFO.

Aircraft Type	LAX No. of Operations[a]	LAX Percent (%)	SFO No. of Operations[a]	SFO Percent (%)
Commercial				
B-747	54	3.7	34	3.7
DC-10	108	7.5	38	4.1
L-1011	50	3.5	24	2.6
B-707	118	8.2	86	9.3
DC-8	46	3.2	46	5.0
B-727	368	25.4	282	30.5
B-737	78	5.4	90	9.7
DC-9	56	3.9	48	5.2
Commuter	204	14.1	92	9.9
General Aviation				
Jet	118	8.2	10	1.1
Prop	173	11.9	134	14.5
Cargo				
B-747	36	2.5	20	2.2
DC-10	36	2.5	20	2.2
TOTAL	1,445	100.0	924	100.0

[a] an operation equals one aircraft movement (e.g., an arrival or a departure); therefore at LAX there are 27 landings and 27 takeoffs of B-747's per day.

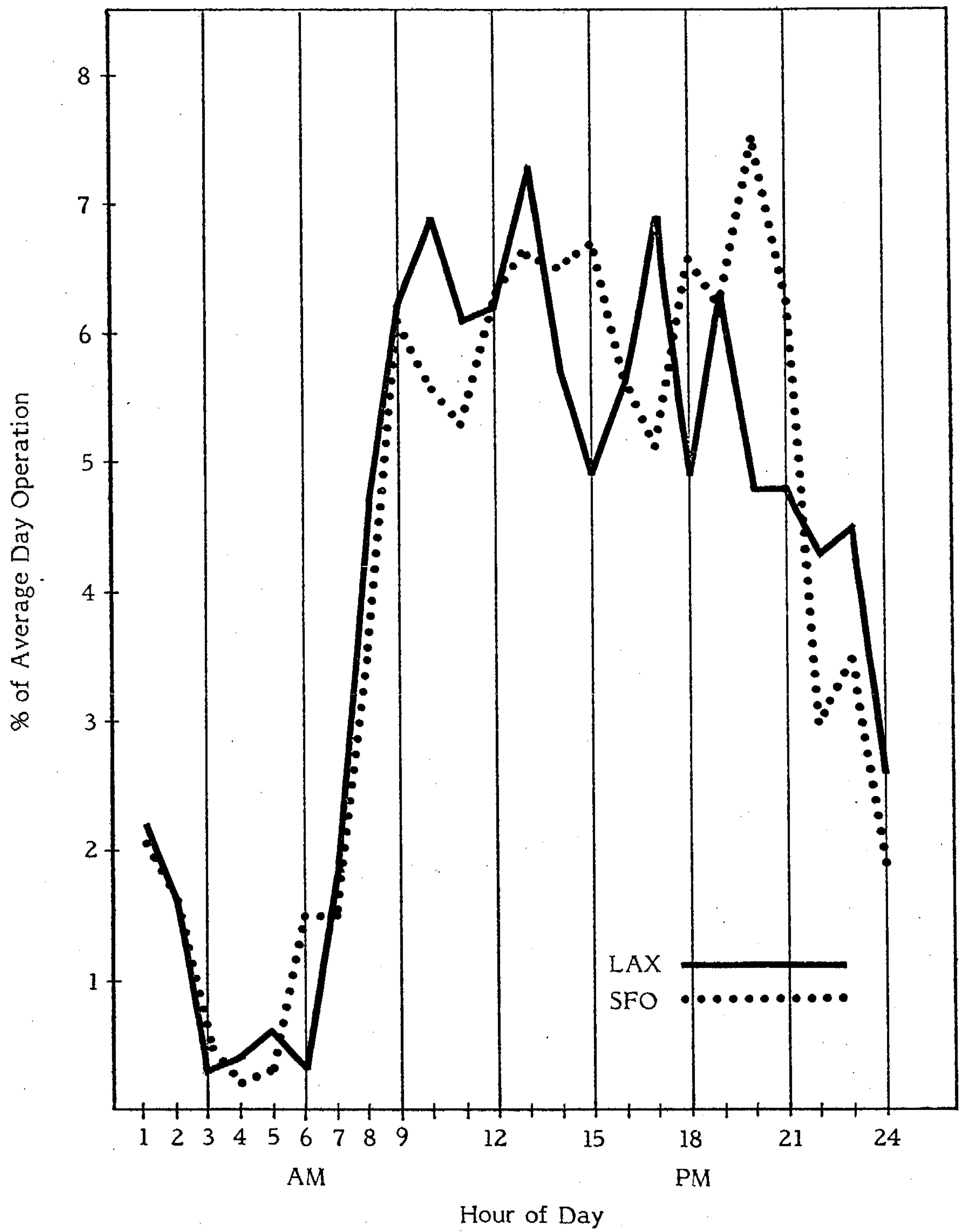

FIGURE 4-1. Distribution of aircraft operations during an average day.

order to estimate taxi distances, the percent of time a given runway configuration occurred during the year was determined from the Federal Aviation Administration (1978). Also, the percent occurrence of VFR (Visual Flight Rules) and IFR (Instrument Flight Rules) conditions was determined. These occurrences are shown in Table 4-2.

Taxi distances were measured from the terminal area to the end of the runway for departures and from the exit point on the runway to the terminal area for arrivals. These distances are shown in Tables 4-3 and 4-4 for LAX and SFO, respectively.

Taxi times were estimated using the travel distance in Tables 4-3 and 4-4 and using an estimated average aircraft taxi speed for arrival and departure. These taxi times for each terminal area for LAX and SFO are shown in Tables 4-5 and 4-6, respectively. Also shown in these tables are the weighted average taxi times (weighted by number of operations) for typical arrival and departure aircraft operations at each airport.

Average aircraft idle times were estimated for operations on an average day. Hourly runway capacity and hourly aircraft demand were determined for both VFR and IFR conditions. Runway capacities were developed using an FAA approved methodology (FAA, 1976). The demand/capacity ratios were used to estimate average aircraft delay (i.e., time spent in idle mode). The amount of delay in the VFR and IFR conditions was weighted according to the percent occurrence (shown in Table 4-2) in order to calculate the average day delay experienced by a typical aircraft operation.

The average time required to pushback aircraft from the gate using a tow tractor was estimated to be 2.0 minutes. This time, during which aircraft engines are started up, was added to the departure idle time.

The takeoff and landing times were estimated to be 1.0 minutes for a typical aircraft operation. Time in mode for idle, taxi, takeoff, and landing for the arrival and departure of a typical aircraft during an average day at LAX and SFO are shown in Table 4-7. These estimates were rounded to the nearest whole minute.

TABLE 4-2. Runway configuration occurrence and VFR/IFR occurrence.

Airport	% Annual Occurrence	Runway Configuration: Arrival	Runway Configuration: Departure	% Annual VFR/IFR
LAX[a]	98%	24 and 25 L/R	24 and 25 L/R	74%/26%
SFO[b]	67%	28 L/R	1 L/R	90%/10%
	25%	28 L/R	28 L/R	90%/10%

[a] the remaining 2% constitute several other runway uses; for estimating emissions and fuel consumption this occurrence was assumed to be 100%.

[b] the remaining 8% constitute several other runway uses; for calculating weighted averages, 73% and 27% were used to approximate the percent occurrence of 28 L/R and 1 L/R versus only 28 L/R, respectively.

TABLE 4-3. Taxi distance by terminal area and runway at LAX.

Terminal Area [a]	Distance To and From Runway (ft)			
	24 L/R		25 L/R	
	Arrival	Departure	Arrival	Departure
North	6,700	3,100	6,300	12,800
South-West	10,300	6,900	1,600	8,300
South-East	11,800	8,200	1,800	7,100
Commuter	5,700	2,200	2,800	4,300
Cargo	15,700	12,100	5,300	3,100
Gen. Aviation [b]	--	--	1,500	1,500

[a] Refer to Figure 3-1 for location of each terminal area. North includes Satellites 2 and 3; South-West includes Satellites 4 and 5; South-East includes Satellites 6 and 7. Commuter, Cargo, and General Aviation are labeled in Figure 3-1.

[b] General aviation aircraft were assumed to use the south runways (25 L/R).

TABLE 4-4. Taxi distances by terminal area at SFO.

Terminal Area[c]	Distance To and From Runway (ft)	
	Arrivals[a]	Departures[b]
Pier B	1,200	7,800
Pier C	1,600	6,300
Pier D	2,500	5,600
Pier E	3,600	4,800
Pier F & FF	5,200	4,600
Pier G	6,000	4,100
Gen. Aviation	4,500	5,300

[a]using runway 28 L/R only

[b]weighted average of 1 L/R and 28 L/R

[c]refer to Figure 3-2 for location of each terminal area. Each pier is labeled in Figure 3-2.

TABLE 4-5. Distribution of average day aircraft operations and taxi times by terminal area and runway at LAX.

Terminal Area	Runway	Number of Operations		Taxi Time (min)	
		Arrival	Departure	Arrival	Departure
North	24 L/R 25 L/R	27 50	75 19	5.1 4.8	1.4 5.8
South-West	24 L/R 25 L/R	23 116	110 33	7.8 1.2	3.1 3.8
South-East	24 L/R 25 L/R	41 174	173 53	9.0 1.4	3.7 3.2
Commuter	24 L/R 25 L/R	0 95	44 49	4.3 2.1	1.0 2.0
Cargo	24 L/R 25 L/R	36 0	36 0	11.9 4.0	5.5 1.4
Gen. Aviation	24 L/R 25 L/R	0 158	0 133	N/A 1.1	N/A 2.0
Total	-	720	725	-	-
Weighted Average	-	-	-	3.0	3.0

TABLE 4-6. Distribution of average day aircraft operations and taxi times by terminal area at SFO.

Terminal Area	Total Number of Operations	Taxi Time (min)	
		Arrival	Departure
Pier B	226	0.7	4.4
Pier C	76	0.9	3.6
Pier D	186	1.4	3.2
Pier E	73	2.0	2.7
Pier F & FF	152	3.0	2.6
Pier G	67	3.4	2.3
Gen. Aviation	144	2.6	3.0
Total	924	-	-
Weighted Average	-	1.8	3.3

TABLE 4-7. Time in mode estimates for a typical aircraft operation.

Mode	Time in Mode (min)[a]	
	LAX	SFO
Departure		
Idle[b]	3.0	4.0
Taxi	3.0	3.0
Takeoff	1.0	1.0
Arrival		
Idle	1.0	2.0
Taxi	3.0	2.0
Landing	1.0	1.0

[a]averaged over a representative day

[b]includes 2.0 minutes for push-back from gate

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DISCLAIMER

The statements and conclusions in this report are those of AeroVironment Inc. and not necessarily those of the California Air Resources Board. The mention of commercial products, their source or their use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such products.

4.2 Aircraft Emissions

Both emissions and fuel consumption were estimated for each mode and each type of aircraft. Pollutant emissions considered were: carbon monoxide (CO); total hydrocarbons (HC); oxides of nitrogen (NO_x); and total suspended particulates (TSP). Sulfur dioxide emissions from aircraft were not considered in this study because modal emission factors have not been determined by aircraft engine type; the emissions are known to be relatively small, however, compared to emissions of the other pollutants.

The following parameters were used to estimate emissions and fuel consumption:

- Number of engines for each aircraft type
- Number of aircraft operations for each type
- Time in mode for: departure – taxi, idle, and takeoff; arrival – taxi idle, and landing
- Emission factors for each: type of mode, aircraft type, and pollutant type, and
- Fuel consumption factors for each type of mode and aircraft.

The number of aircraft operations and time in mode were previously shown in Tables 4-1 and 4-7, respectively. Fuel consumption factors, number of engines, and emission factors for CO, HC, and NO_x were obtained from a recently published EPA technical report on aircraft emission factors (Pace, 1977). Emission factors for TSP were obtained from an EPA (1977) publication on compilation of air pollutant emission factors. Fuel consumption was converted from pounds to gallons by using a fuel density factor (6.67 lbs/gal) obtained from the EPA (1973).

Since emission factors were presented by type of engine, appropriate engine types were selected that corresponded to aircraft type. In the case where more than one type of engine could be appropriate, an average was used. Table 4-8 presents the engine types used to determine emission factors for each aircraft type.

Emission factors for the four pollutants, fuel consumption factors, and number of engines used to estimate the emissions are shown in Table 4-9. Since neither of the EPA emission factor publications contained a factor for landing, the following equation was used to determine the landing emission and fuel use rate for each aircraft type:

$$EF_L = 0.6\ EF_I + 0.16 EF_A + 0.24 EF_T$$

where,	EF	=	Emission Factor (and Fuel Use Factor)
	L	=	Landing
	I	=	Idle
	A	=	Approach
	T	=	Takeoff

This equation was obtained from an EPA-sponsored study (EPA, 1973) which provided an overall methodology for determining air pollutant emissions at airports.

Emissions were also estimated for the Auxiliary Power Unit (APU), which supplies both hydraulic and electrical power to the aircraft while it is parked at the gate. However, B-707's and DC-8's are not equipped with an APU. They obtain their power requirements from a Ground Power Unit (GPU) which is usually mounted on a service vehicle. Emissions from GPU's are presented later in this report.

Emission factors for APU's were obtained from an EPA report (EPA, 1971). These factors are as follows:

TABLE 4-8. Type of engines for each aircraft type.

Aircraft Type	Engine Types Used for CO, HC, and NO_x	Engine Types Used for TSP
Commercial and Cargo		
B-747	P&W JT9D-7 P&W JT9D-70 RR RB211-524	P&W JT9D
DC-10	GE CF6-50C	GE CF6
L-1011	RR RB211-524 RR RB211-22B	P&W JT9D GE CF6
B-707	P&W JT3D-7	P&W JT3D
DC-8	P&W JT3D-7	P&W JT3D
B-727	P&W JT8D-17	P&W JT8D
B-737	P&W JT8D-17	P&W JT8D
DC-9	P&W JT8D-17	P&W JT8D
Commuter	Garrett TPE 331-2 Garrett TPE 331-3	Garrett TPE 331
General Aviation		
Business Jet	P&W JT 15D-1 GE CJ610-6 Garrett TFE 731-2 GE CF700	P&W JT8D RR SPREY MK511
Prop	Tele. Cont. TS10-360C Avco Lycoming T10-540	Tele. Cont. 200 Lycoming 320

TABLE 4-9. Emission factors and fuel consumption factors by aircraft type and mode.

Aircraft Type	No. of Engines	Factors (lbs/hr per engine)														
		Idle/Taxi					Landing					Takeoff				
		Fuel Usage	CO	HC	NO_x	TSP	Fuel Usage	CO	HC	NO_x	TSP	Fuel Usage	CO	HC	NO_x	TSP
Commercial																
B-747	4	1806	79.8	24.3	5.4	2.2	6204	52.4	15.5	149.9	2.6	17990	4.8	1.9	578.6	3.8
DC-10	3	1206	88.0	36.2	3.0	neg.	6104	56.5	21.8	171.3	0.2	18900	0.4	0.2	671.1	0.5
L-1011	3	1744	86.8	52.8	5.0	1.1	5749	62.1	38.0	150.3	1.4	16320	6.5	15.6	582.2	2.2
B-707	4	1013	140.8	124.6	2.2	0.4	3491	96.3	77.0	34.3	3.5	9956	9.0	5.0	126.4	8.2
DC-8	4	1013	140.8	124.6	2.2	0.4	3491	96.3	77.0	34.3	3.5	9956	9.0	5.0	126.4	8.2
B-727	3	1150	39.1	10.1	3.9	0.4	3535	28.4	6.4	54.1	1.4	9980	7.0	0.5	202.6	3.7
B-737	2	1150	39.1	10.1	3.9	0.4	3535	28.4	6.4	54.1	1.4	9980	7.0	0.5	202.6	3.7
DC-9	2	1150	39.1	10.1	3.9	0.4	3535	28.4	6.4	54.1	1.4	9980	7.0	0.5	202.6	3.7
Commuter/ Turboprop	2	109	6.8	9.2	0.3	0.3	206	4.6	5.6	1.7	0.5	432	0.4	0.1	4.9	0.8
General Aviation																
Bus. jet	2	342	45.2	7.2	0.5	0.3	823	42.0	4.7	4.9	2.8	2086	33.9	0.2	17.6	9.8
Prop.	2	18	19.6	1.6	neg.	0.3	71	88.8	1.6	0.1	0.5	196	259.2	2.2	0.2	0.8

Pollutant	Emission Factor (lb/hr)
CO	1.99
HC	0.04
NO_x	1.03
TSP	(data not available)

Since the emission factors are in units of pounds per hour, the following approximate operational times were used to estimate emissions for each aircraft type (general aviation aircraft are not equipped with APU's):

- For B-747, DC-10, and L-1011 – 80 minutes

- For B-727, B-737, and DC-9 – 40 minutes

These operational times were obtained from the same reference used for the APU emission factors. Emissions were estimated by multiplying the number of operations by the operational time and the emission factor.

Although Table 4-7 shows the averaged time in mode for a typical aircraft, more detailed taxi times by terminal area were presented in Tables 4-5 and 4-6 for LAX and SFO, respectively.

A more detailed calculation was performed for LAX which involved the estimation of aircraft emissions for each terminal area. This not only gives a more realistic baseline emission estimate reflecting the heavy concentration of aircraft operations around the south terminal areas, but also allows a more accurate analysis of the impact of reassigning aircraft to runways based on minimum taxi distance.

This same detailed calculation was not performed for SFO because the runway usage at SFO can be more clearly defined. Arrivals generally land on Runways 28 L/R and departures generally take off on Runways 1 L/R. Therefore, runway assignment would not have significant impacts on aircraft taxi distance. Whereas at LAX, aircraft can use either Runways 24 L/R or

25 L/R for landings and takeoffs if weight and noise restrictions are not a factor. Also, terminal areas at SFO are more centrally located (relative to the runways) than those at LAX and, consequently, taxi distance would be less affected by reassignment of runways.

Table 4-10 presents the distribution of the number of aircraft operations at LAX by aircraft type, arrival or departure, terminal area, and runway.

This data, in addition to the taxi times in Table 4-5, was used to estimate emissions and fuel consumption from aircraft at LAX. For SFO, Tables 4-1 and 4-7 were used for averaged emission estimates.

A summary of the aircraft emissions and fuel consumption is shown in Table 4-11. This table shows that for CO and HC the largest contribution is from idle and taxi operations, while for NO_x the takeoff operation contributes the greatest portion of the emissions. The magnitude of the TSP emission appears to be quite small in comparison to the other pollutants.

At LAX, Table 4-12 presents a breakdown of percent emissions by terminal area. These percent contributions are for total operations which includes idle, taxi, takeoff, and landing. APU operations were not included.

4.3 Ground Equipment Operations and Emissions

Three types of ground equipment operations were considered in estimating emissions: ground service vehicles; fuel handling and storage; and aircraft engine maintenance.

For ground service vehicles, the following parameters were used to estimate emissions and fuel consumption:

- o Number of aircraft operations for each aircraft type
- o Time required to service each aircraft for each type of ground service vehicle

TABLE 4-10. Distribution of average day aircraft operations by terminal area and runway at LAX.

Terminal	Runway	Number of Aircraft Operations																						Total For Each Terminal
		Arrivals											Departures											
		B-747	DC-10	L-1011	B-707	DC-8	B-727	B-737	DC-9	Comm. T. P.	G. A. Jet	G. A. Prop.	B-747	DC-10	L-1011	B-707	DC-8	B-727	B-737	DC-9	Comm. T. P.	G. A. Jet	G. A. Prop.	
North	24 L/R	6	6	15	0	0	0	0	0	0	-	-	13	8	14	31	3	5	1	0	0	-	-	102
	25 L/R	0	0	0	24	2	22	1	1	0	-	-	0	0	0	0	1	16	0	2	0	-	-	69
South-West	24 L/R	6	17	0	0	0	0	0	0	0	-	-	6	23	0	25	0	26	30	0	0	-	-	133
	25 L/R	0	6	0	37	0	43	30	0	0	-	-	0	0	0	0	0	33	0	0	0	-	-	149
South-East	24 L/R	13	17	8	0	3	0	0	0	0	-	-	10	24	10	1	18	83	8	14	5	-	-	214
	25 L/R	0	7	3	0	17	104	8	27	8	-	-	0	0	0	0	2	36	0	12	3	-	-	227
Commuter	24 L/R	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-	-	-	-	-	44	-	-	44
	25 L/R	-	-	-	-	-	-	-	-	95	-	-	-	-	-	-	-	-	-	-	49	-	-	144
Cargo	24 L/R	18	18	-	-	-	-	-	-	-	-	-	18	18	-	-	-	-	-	-	-	-	-	72
	25 L/R	0	0	-	-	-	-	-	-	-	-	-	0	0	-	-	-	-	-	-	-	-	-	0
General Aviation	25 L/R	-	-	-	-	-	-	-	-	-	65	93	-	-	-	-	-	-	-	-	-	53	80	291
		43	71	26	61	22	169	39	28	103	65	93	47	73	24	57	24	199	39	28	101	53	80	1445
		720											725											

TABLE 4-11. Summary of emissions and fuel consumption from average day aircraft operations at LAX and SFO.

Type of Operation	LAX					SFO				
	Fuel	CO	HC	NO_x	TSP	Fuel	CO	HC	NO_x	TSP
Idle										
Arr.	5.58	1.19	0.62	0.05	neg.	6.50	1.38	0.79	0.07	0.01
Dep.	14.99	3.15	1.69	0.15	0.03	12.90	2.74	1.58	0.13	0.02
Total	20.57	4.34	2.31	0.20	0.03	19.40	4.12	2.37	0.20	0.03
Taxi										
Arr.	19.96	4.12	2.08	0.19	0.04	6.50	1.38	0.79	0.07	0.01
Dep.	16.28	3.16	1.64	0.16	0.03	9.70	2.06	1.18	0.10	0.01
Total	36.24	7.28	3.72	0.35	0.07	16.20	3.44	1.97	0.17	0.02
Takeoff	50.03	0.45	0.03	4.19	0.06	31.20	0.36	0.02	2.42	0.04
Landing	19.84	0.94	0.39	1.34	0.03	10.90	0.55	0.24	0.63	0.01
APU	NA	0.30	0.01	0.16	NA	NA	0.20	neg.	0.11	NA
Total	126.68	13.31	6.46	6.24	0.19	77.70	8.67	4.60	3.53	0.10

NA – not available

Note: fuel consumption units – 10^3 gal/day
emission units – tons/day

TABLE 4-12. Percent contribution of aircraft emissions by terminal area at LAX.

Terminal Area	Percent Contribution (%)			
	CO	HC	NO_x	TSP
North	20	30	18	16
South-West	22	24	23	21
South-East	31	31	36	32
Commuter	1	2	neg.	neg.
Cargo	18	12	23	21
Gen. Aviation	8	1	neg.	10

<u>Note</u>: includes idle, taxi, takeoff, and landing modes for an average day

- o Fuel consumption factors for each ground vehicle type for gasoline and diesel fuel, and

- o Emission factors for gasoline fuel and diesel fuel consumption for CO, HC, NO_x, and TSP.

The number of aircraft operations were presented in Table 4-1. Service times and fuel use rates are shown in Table 4-13 for each ground service vehicle type. Emission factors used to estimate emissions are as follows:

	Emission Factors (lbs/10^3 gals)	
Pollutant	Gasoline	Diesel
CO	1,797	325
HC	282	65
NO_x	124	340
TSP	11	25

Service times, fuel consumption, and emission factors for ground service vehicles were obtained from the Federal Aviation Administration (1974) and the Environmental Protection Agency (1973). Data from the EPA (1973) were used for the ground power units, while data from the FAA (1974) were used for all other vehicle types.

Table 4-14 presents the fuel consumption and emission estimates from ground service vehicles at LAX and SFO.

Data on emissions from fuel handling and storage, as well as engine maintenance, were obtained from previous studies and reports. Data for LAX was published in 1971, while the data for SFO was published in 1975. Personal communication with the L.A. Department of Airports, Engineering Bureau (1978) indicated that no modification of fuel storage facilities has occurred since 1970. Although the amount of fuel handled at LAX and SFO

TABLE 4-13. Service times and fuel consumption by ground service vehicle type.

Vehicle Type	Service Time (min)								Fuel Use (gal/hr)
	B-747	DC-10	L-1011	DC-8	B-727	B-707	DC-9	B-737	
Light duty tractor	40	20	48	20	19	20	23	24	1.8
Belt loader	15	18	15	53	18	53	8	16	0.7
Container loader	90	35	50	0	8	0	.5	0	1.8
Cabin service	30	15	15	15	6	15	9	1	1.5
Lavatory truck	15	10	20	10	10	10	6	7	1.5
Water truck	15	10	15	10	7	10	4	7	1.5
Food service truck	20	15	20	15	15	15	10	7	2.0
Fuel truck	25	20	20	20	15	20	11	16	1.7
Tow tractor	5	5	5	5	2	5	2	2	2.4
Air conditioner	0	0	0	0	2	0	0	0	1.8
Airstart	0	0	0	0	.3	0	0	0	1.4
Ground power unit									
Truck engine	0	0	0	9	0	9	0	0	2.0
Power unit (gas)	0	0	0	40	0	40	0	0	5.0
Power unit (diesel)	0	0	0	40	0	40	0	0	7.1

TABLE 4-14. Fuel consumption and emissions from ground service vehicles.

Category	LAX		SFO		Total	
	Gas	Diesel	Gas	Diesel	LAX	SFO
Fuel Use (gal/day)	1,747	388	1,235	312	2,135	1,547
Pollutants (ton/day)						
CO	1.57	0.06	1.11	0.05	1.63	1.16
HC	0.25	0.01	0.17	0.01	0.26	0.18
NO_x	0.11	0.07	0.08	0.05	0.18	0.13
TSP	0.01	neg.	0.01	neg.	0.01	0.01

has most likely increased with time, the percent change in emission would be small in comparison to total aircraft emissions. Therefore, additional effort was not made to quantify this amount.

Table 4-15 presents the emission estimates from fuel handling, fuel storage, and engine maintenance. Also shown in this table are the references used to obtain the data. The ABAG report used for the SFO maintenance emissions includes only the emissions from the overhaul test cells, and not from other routine maintenence. To arrive at total maintenance emissions, the LAX maintenance data was multiplied by 0.64 (the ratio of SFO aircraft operations to LAX), and the result was added to the overhaul test emissions.

4.4 Baseline Emission Summary

Data were compiled from Tables 4-11, 4-14, and 4-15 to summarize total airfield ground level emissions. This summary is presented in Table 4-16.

Table 4-17 identifies the relative contribution of each category of source emissions to the total airfield ground emissions. It appears that the greatest percent contribution of CO and HC emissions is from the taxi and idle modes for aircraft operations. For NO_x, the aircraft takeoff mode contributes the largest percent of the total emissions. For TSP, the largest percent contribution seems to result from the combination of aircraft idle, taxi, and takeoff modes.

The contribution from ground equipment sources appear to be small in comparison to aircraft operations. However, additional effort would be required to more accurately quantify these emissions.

For comparison, the estimated total emissions from all sources related to the airports in 1975 are shown in Table 4-18. These data are from three different reports (two sets of data are shown for SFO) which were prepared

TABLE 4-15. Emissions from fuel handling, fuel storage, and aircraft engine maintenance.

Airport/Category	Emissions (tons/day)				References
	CO	HC	NO_x	TSP	
LAX					
Fuel Handling	-	0.15	-	-	LAAPCD (1971)
Fuel Storage	-	0.60	-	-	LAAPCD (1971)
Aircraft Engine Maintenance	1.4	1.7	0.08	NA*	LAAPCD (1971)
SFO					
Fuel Handling	-	0.11	-	-	ABAG (1972)**
Fuel Storage	-	0.15	-	-	San Francisco Airport Commission (1975)
Aircraft Engine Maintenance	1.9	1.5	0.6	NA*	ABAG (1972)** and LAAPCD (1971)

* Because of extensive modifications to aircraft engines, the 1971 LAAPCD data no longer reflect current TSP emissions.

** SFO data reflects estimates for 1975.

TABLE 4-16. Summary of total airfield ground-level emissions at LAX and SFO.

Airport/Category	Pollutant Emissions (tons/day)			
	CO	HC	NO_x	TSP
LAX				
Aircraft Operations	13.31	6.46	6.24	0.19
Service Vehicles	1.63	0.26	0.18	0.01
Fuel Handling & Storage	-	0.75	-	-
Engine Maintenance	1.40	1.70	0.08	NA
Total	16.34	9.17	6.50	0.20
SFO				
Aircraft Operations	8.67	4.60	3.53	0.10
Service Vehicles	1.16	0.18	0.13	0.01
Fuel Handling & Storage	-	0.26	-	-
Engine Maintenance	1.90	1.50	0.60	NA
Total	11.73	6.54	4.26	0.11

NA - not available (probably a small fraction of the total given)

TABLE 4-17. Percent* contribution of airfield source emissions and fuel consumption at LAX and SFO.

Source Category	% Contribution - LAX					%Contribution - SFO				
	Fuel	CO	HC	NO_x	TSP	Fuel	CO	HC	NO_x	TSP
Aircraft Operations										
Idle	16	26	25	3	15	25	35	37	5	27
Taxi	28	44	41	5	35	20	30	30	4	18
Takeoff	39	3	neg.	65	30	39	3	neg.	56	37
Landing	15	6	4	21	15	14	5	4	15	9
APU	NA	2	neg.	2	NA	NA	2	neg.	3	NA
Total	98	81	70	96	95	98	75	71	83	91
Ground Equipment										
Service Vehicles	2	10	3	3	5	2	10	2	3	9
Fuel Handling & Storage	-	-	8	-	-	-	-	4	-	-
Engine Maintenance	NA	9	19	1	NA	NA	15	23	14	NA
Total	2	19	30	4	5	2	25	29	17	9

NA - not available
*Percentage of the total aircraft ground operations and ground equipment emissions

TABLE 4-18. Summary of total airport-related emissions* at LAX and SFO in 1974 or 1975, as published in various environmental reports.

Airport/Category	Pollutant Emissions (tons/day)				
	CO	HC	NO_x	TSP	SO_2
LAX					
Aircraft	37	18	13	1.5	1.4
Non-aircraft	86	16	17	1.6	0.5
Total	123	34	30	3.1	1.9
SFO					
Aircraft	23/10	12/6	10/6	7.4/0.4	2.1/0.1
Non-aircraft	7/11	1/1	1/1	0.4/0.2	0.1/0.4
Total	30/21	13/7	11/8	7.8/0.6	2.2/0.5

Sources: LAX - Olson Laboratories (1975)
SFO - ABAG (1972)/San Francisco Airport Commission (1975)

*includes auto traffic and low altitude in-flight emissions at different times using somewhat different methods and emission factors, and thus are not wholly consistent with each other nor with the data presented in this report. Nevertheless, the numbers do illustrate the magnitudes involved; comparison with Table 4-16 shows that the airfield ground operations account for approximately 15 to 30% of the total airport emissions, 30 to 50% of the HC emissions, 20 to 35% of the NO_x emissions, and less than 10% of the TSP emissions. Although the absence of adequate SO_2 data precluded the inclusion of SO_2 in Table 4-16, Table 4-18 shows some estimates of total airport SO_2 emissions.

5. PRELIMINARY STRATEGY EVALUATION

This chapter presents the identification of potential strategies, preliminary evaluation of strategies, and selection of strategies for further analysis and examination.

5.1 Strategy Identification

Five general categories of strategies were developed which define a modification or change in airfield operations that would reduce total airfield emissions. These categories are discussed below.

1) Engine Shut-Down - strategies which would reduce the time that aircraft engines are operating and emitting pollutants.

2) Volume and Type of Operations - strategies aimed at reducing the total number of aircraft operations and at changing the types (or mix) of aircraft that use the airport since some types generate more emissions than others.

3) Gate Operating Practices - strategies which would control emissions while the aircraft was located in the gate area.

4) New Construction - strategies aimed at increasing the overall efficiency and reducing delays by improving the airfield facilities.

5) Air Traffic Control Procedures - strategies which would improve the landing/takeoff and taxi procedures and thereby reducing aircraft emissions.

Table 5-1 presents individual strategies identified according to the five general categories. These 19 strategies represent a comprehensive review of feasible measures to control the airfield ground emissions.

TABLE 5-1. Strategies identified for preliminary evaluation.

Engine Shut-Down	
1)	Tow Aircraft
2)	Underground Cable
3)	Reduce Number of Engines
Volume and Type of Operations	
4)	Passenger Load Increase
5)	Fleet Mix Control
6)	Establish Peak Period Quota
Gate Operating Practices	
7)	Use Ground Power at Terminal
8)	Delay Engine Start-Up
9)	Modify Refueling Practices
New Construction	
10)	Construct New Taxiways
11)	Build More Gates
12)	Construct New Holding Areas
13)	Strengthen Sepulveda Tunnel (LAX only)
14)	Redesign Passenger Boarding Facilities
Air Traffic Control Procedures	
15)	Alternative Deceleration Pattern
16)	Special General Aviation Procedures
17)	Power versus Tow to Maintenance (SFO only)
18)	Control Departure Times
19)	Runway Assignment

5.2 Preliminary Evaluation

Ranges for emission savings, fuel savings, and impacts associated with strategy implementation are shown in Table 5-2. These ranges were developed in order to determine relative magnitudes of savings and impacts between strategies.

Strategies were evaluated by examining the operational parameters affected (e.g., taxi distance, delays, emission characteristics, type of aircraft) and by approximating the amount of emissions and fuel savings which could result from changes in each parameter. Also, the range of impact which might result from strategy implementation were determined. This evaluation was based on qualitative estimates of strategy effects on airfield operations.

The following presents for each of the 19 strategies: (1) description; (2) the potential range of emission and fuel savings; and (3) a discussion of safety impact, cost impact, and time factor. A general discussion on jurisdictional and regulatory conflicts is presented later in this section.

1) Tow Aircraft

- Description - This strategy would reduce aircraft taxi emissions by requiring that each aircraft be towed between the runway and terminal. At LAX, towing would be implemented for: departing aircraft leaving the south terminal areas for runways 24 L/R and 25 L/R; departing aircraft leaving the north terminal area for runway 25 L/R; arriving aircraft on 24 L/R taxiing to either the north or south terminal; and arriving aircraft on 25 L/R taxiing to the north terminal. At SFO, only departing aircraft would be towed to runways 1 L/R and 28 L/R. Arrivals on runway 25 L/R taxiing to the south terminal at LAX and all arrivals on runway 28 L/R at SFO were not considered for towing since after clearing the runway these aircraft are essentially at the terminal

TABLE 5-2. Ranges for strategy implementation used in preliminary evaluation.

Savings/Impacts	Range
Emission and Fuel Savings	N = Negligible (less than 5%) L = Low (between 5% and 25%) M = Medium (between 25% and 50%) H = High (over 50%)
<u>Associated Impacts</u>	
Safety	P = Potential safety problem (FAA safety requirements may not be satisfied) S = No apparent safety problems (FAA safety requirements satisfied
Costs	N = Negligible (less than $50,000) L = Low (between $50,000 and $500,000) M = Medium (between $500,000 and $1,000,000) H= High (over $1,000,000)
Time	I = Immediate (within 2 years) NT = Near Term (within 5 years) LT = Long-Term (more than 5 years)

area. Towing of commuter, turboprop, and general aviation were also not considered, since their emission contribution is small in comparison to passenger commercial aircraft. It was assumed that the types of tractors now in use would be used for towing. New technology tractors were not examined.

- Emission and Fuel Savings - At LAX, high emission savings could result for departures and a medium savings for arrivals in the idle and taxi modes. A medium increase in ground service emissions could be experienced. At SFO, a high emissions savings could occur for departures in the idle and taxi mode. No reduction would be available for arrivals. A low increase in ground service vehicle emissions could result from additional tow tractors. Also, a medium savings and low savings could result in aircraft fuel consumption at LAX and SFO, respectively.

- Safety - A number of safety issues need to be resolved before this strategy can be implemented. Among these issues are: (1) reliability of aircraft nose gear structure under the stress of long distance towing; (2) control of aircraft is placed on the tug driver rather than the pilot, although the latter is legally responsible for the safety of passengers and aircraft; (3) training and certification of tug driver; (4) difficulty in engine start-up under adverse wind conditions if adequate space is not available to position the aircraft favorably; (5) need for engines to attain thermal stability before takeoff, which implies that a large area at the departure end of the runway would be needed; and (6) adequate space for coupling aircraft to the tow tractor after the aircraft has cleared the runway.

- Cost - Implementation of this strategy could provide significant cost savings in fuel consumption. This will be offset by the need to acquire tractors, tow bars, communication equipment, fuel consumption by tractors, additional starter trucks required, additional tractor crew members, training of tractor crews, fire-fighting equipment at engine start-up area, construction of additional ramps and roadways, increased flight crew block time, and potential need to purchase APU's for aircraft not equipped with one. In addition, longer ground time decreases aircraft utilization and may require some carriers to add aircraft to their fleets to maintain schedule. The overall impact on annual costs is likely to be high.

- Time Factor - Full scale towing probably will not be implemented until safety and other issues are resolved. It is estimated that this would not happen in less than five years.

2) Underground Cable

- Description - This strategy reduces the aircraft engine emissions occurring during taxi operations from the apron to the runway and vice versa. This strategy is similar to towing, in that engines are shut off during the movement of the aircraft to and from the runways and gates. The underground cable system is basically a continuous moving cable located under the taxiways and powered by a generator. The aircraft clamps onto the cable and is pulled along until it is released by letting up on the clamp. This system could be engineered in such a way as to allow maximum pilot control.

- Emission and Fuel Savings - The savings from this strategy could be about the same as those obtained from the aircraft towing strategy. The only difference being that emissions from tow tractors would not be generated.

- Safety - The safety aspects of this strategy have not been demonstrated. It appears that some of the safety issues related to aircraft towing would probably apply to this strategy.

- Cost - It is estimated that the cost impacts of this strategy are very high, much higher than towing due to the capital investment and new construction.

- Time Factor - Due to the many unresolved factors on safety as well as financial burden on the airport operator and airlines, the implementation of this strategy would most likely be in the long-term time frame.

3) Reduce Number of Aircraft Engines

- Description - This strategy would achieve emission reductions in two ways: (1) fewer engines operating during taxi and idle modes, and (2) more efficient combustion of the remaining engines that must operate at a higher power setting to maintain taxi speed. However, since temperatures are increased at higher power settings, NO_x emissions would be increased instead of being reduced.

- Emission and Fuel Savings - A medium savings in CO and HC emissions and a low increase in the NO_x emissions could result. These estimates assume that all commercial aircraft will shut down one engine during taxi and idle. A negligible savings in fuel consumption would probably result.

- Safety - The FAA has recommended, as documented in FAA (1974) Advisory Circular AC-91-41, that "when clear of the runway after landing, or in a delay absorbing area, four-engine turbojet aircraft should shut down one or two engines. Three-engine turbojet aircraft should shut down one engine. The taxi procedure is not recommended under the following conditions: (1) when auxiliary power units are inoperative on aircraft so equipped, or when power requirements otherwise preclude shut down; (2) during adverse weather conditions such as ice, sleet, or snow, and (3) under any conditions that the pilot-in-command considers to be hazardous, operationally unsuitable or creating undue passenger discomfort."

- o Cost - The additional fuel required to keep the operating engines at a higher power setting and the fuel saved by shuting down one engine will most likely balance out to be a low cost impact.

- o Time Factor - With the recent FAA Advisory Circular, it appears that this strategy could be implemented in the immediate future, or may already be in practice with some of the airlines.

4) Passenger Load Increase

- o Description - By increasing the occupancy of available seats, fewer aircraft would be required to transport the same number of people. This strategy would reduce aircraft emissions more than proportionately because delays increase exponentially as traffic activity increases.

- o Emission and Fuel Savings - Average passenger load factors are between 50% and 60% under existing conditions. Increasing the load factor by 5% could reduce airfield emissions and fuel consumption between 5% and 10% (i.e., low emission savings).

- o Safety - No safety problems are anticipated.

- o Cost - When considering the effects of this strategy on LAX and SFO, cost impacts are likely to be negligible. However, this strategy may have significant effects on domestic and international route networks and schedules at other airports. It is difficult, and beyond the scope of this study, to estimate what the cost implications would be on other airports.

- o Time Factor - Since regulatory actions would be required, any possible implementation of this strategy can only be achieved in the near to long-term.

5) Fleet Mix Control

- o Description - This strategy would impose restrictions on the use of aircraft that produce high emissions per passenger by accelerating the use of newer wide-body aircraft which produce lower emissions per passenger.

- o Emission and Fuel Savings - An estimate of percent reduction was determined by assuming all B-707's and DC-8's would be replaced (based on seating capacity) with a combination of B-747's, DC-10's, and L-1011's. This could result in a medium reduction of emissions but fuel savings would probably be in the low range due to the smaller differences in fuel consumption rates between older and newer aircraft.

- o Safety - No safety problems are anticipated.

- o Cost - This strategy could have an extremely high cost impact. A tremendous financial burden would be placed on the airlines to replace older aircraft with newer equipment.

- o Time Factor - Implementation of this strategy will probably occur in the near to long-term due to time requirement in ordering and purchasing new aircraft.

6) Establish Quotas

- o Description - This strategy would specify the maximum number of aircraft that may land or take off in a given period. This would mean a reduction in traffic levels during peak periods and an increase in traffic activity in adjacent off-peak periods. Reductions in aircraft emissions from reduced idle times in the peak period would be partially offset from increased idle emissions in the adjacent periods.

- Emission and Fuel Savings - Negligible savings will occur since the savings which could be obtained during the peak periods would be offset in adjacent periods.

- Safety - No safety problems are anticipated.

- Cost - Cost impacts might be beyond the airports under study (i.e., LAX and SFO). Impacts on other airports resulting from the restriction of flights during peak periods are difficult to estimate and beyond the scope of this study. However, cost impacts at LAX and SFO would most likely be negligible.

- Time Factor - Presently, average day demands at either LAX or SFO have not yet reached capacity levels. In the near term, peak period quotas may need to be established at both airports.

7) Use of Ground Power at Terminal

- Description - This strategy is aimed at eliminating the use of auxiliary power units (APU) while aircraft are loading and unloading at the terminal gate. Since most commercial aircraft are equipped with APU's (small on-board jet engines), they are used to provide both electrical and pneumatic power. APU's allow aircraft to be a self-contained unit. They also burn fuel while being operated. Therefore, eliminating the use of APU's and switching to ground power units (GPU's) at the terminal would result in excluding APU emissions.

- Emission and Fuel Savings - This strategy would result in a high reduction of APU emissions but, at the same time, create a low increase in ground service vehicle emissions, primarily GPU's.

- Safety - No safety problems are anticipated.

- Cost - The purchase of ground power units at the terminal would require substantial capital investment. The costs of this strategy are likely to be in the medium range.

- Time Factor - Implementation would probably be in the near term time frame due to the time requirement for ordering and purchasing the GPU's.

8) Delay Start-Up Until Push-Back

- Description - This strategy would reduce aircraft engine emissions by requiring airlines to delay engine start-up until the push-back operation is completed from the gate position.

- Emission and Fuel Savings - Currently, push-back from the gate is performed while engines are operating. This strategy would require delaying engine start-up until completion of push-back. However, an engine warm-up period is necessary before an aircraft starts to taxi out to the runway. This warm-up is now being done during the push-back phase. The net result is a negligible savings since the overall engine operating time would not be reduced.

- Safety - Since push-back operations are already in practice, no safety problems attributable to this strategy are anticipated. The congestion in the apron-ramp caused by the delay in engine start-up may result in higher conflict incidence which would require additional attention from the controllers.

- Cost - Any cost impacts are likely to be negligible.

- Time Factor - Could be implemented immediately.

9) <u>Modify Refueling Practices</u>

- Description - Hydrocarbon emissions from fuel handling and storage have two primary sources: breathing losses and working losses. When vapor recovery systems are installed on the storage tanks breathing losses become negligible. Working losses occur when vapors are displaced by filling the tank with fuel where the vapors escape through venting to the atmosphere. Control of these working losses when refueling aircraft can be accomplished by recovering the vapors normally vented to the atmosphere. These vapors are then compressed and condensed into a liquid and recycled back into the fuel storage tank.

- Emission and Fuel Savings - Since the majority of the fuel storage and handling equipment at both LAX and SFO contain vapor recovery systems, it appears that additional control could only achieve a low savings at most.

- Safety - No safety problems are anticipated.

- Cost - This strategy would require the installation of additional vapor recovery systems and recycle systems further to reduce hydrocarbon emissions from fuel handling and storage. The initial capital costs are probably quite high. The annualized costs, however, are estimated to be in the medium range.

- Time Factor - This strategy could be implemented in the near term.

10) Construct New Taxiways

- o Description - This strategy of new parallel taxiways would provide flexibility in aircraft taxi routing, minimize the possibility of conflicts, and reduce the time spent by aircraft in the idle modes.

- o Emission and Fuel Savings - Negligible savings. The existing taxiway system is adequate in most cases. Occasionally, taxiway congestion may occur. However, additional taxiways would probably not produce more than a 5% savings in overall aircraft emissions.

- o Safety - There are no safety problems anticipated.

- o Cost - The cost to build new taxiways would be high.

- o Time Factor - A near-term time frame would appear to be a reasonable estimate for implementation.

11) Build More Gates

- o Description - This strategy would reduce the time arriving aircraft must spend waiting for gate positions. The reduction in waiting time, in turn, would alleviate congestion and patterns would be smoother and more efficient and less time would be spent in idle mode.

- o Emission and Fuel Savings - Under existing demand, the number of gates at LAX is adequate except for occasional congestion during peak periods due to intrahour scheduling. The addition of two or three gates is not likely to produce more than a 5% reduction in aircraft emissions. Therefore, savings are negligible. At SFO, the airport construction program is keeping pace with air traffic demand. Therefore, emission savings are negligible.

- o Safety - No safety problems are anticipated.

- o Cost - If additional gates are required, the estimated costs for gate construction are quite high.

- o Time Factor - In the long run, additional gates are needed as demand continues to grow. Gates could be built in the near term.

12) Build New Holding Areas

- o Description - Without holding areas, aircraft waiting for gate positions impede the flow on the taxiways. Holding areas reduce taxiway congestion as well as unnecessary aircraft emissions in the arrival idle mode. By constructing can be accommodated without impeding the normal flow on the taxiway system.

- o Emission and Fuel Savings - Savings in aircraft emissions are likely to be negligible at LAX and SFO. This is because holding areas will only be needed during peak periods and usually no more than two or three aircraft are in the holding area. At SFO, the area around Pier finger G is used as a holding area when necessary. There is also a lack of space on the airfield that would provide a convenient holding area without adding significantly to aircraft taxi distance.

- o Safety - No safety problems are expected.

- o Cost - At present, SFO already has sufficient holding area to accommodate existing needs. For LAX, recommendations have been made to build temporary holding areas on existing taxiway

47 west of Satellites 3 and 4. The estimated cost of constructing holding areas range from medium to high, depending on final requirements.

- Time Factor - It is estimated that the implementation of this strategy is probably within the near-term.

13) Strengthen Sepulveda Tunnel

- Description - This strategy applies to Los Angeles International Airport only. Because of weight restrictions, wide-body aircraft weighing more than 325,000 pounds are currently prohibited from using Runway 25L and those taxiways which cross the Sepulveda Boulevard Tunnel. This restricts the efficiency of the runway system and results in delays to aircraft. Strengthening the Sepulveda underpass would remove this constraint, allow more flexible and efficient operations, and reduce taxi and idle emissions.

- Emission and Fuel Savings - This strategy would most likely give a low emissions savings in both arrival and departure taxi time and negligible emissions savings in delay/idle time. Fuel savings is likely to be negligible.

- Safety - No safety problems are anticipated.

- Cost - It is estimated that cost impacts of this strategy are likely to be quite high, since strengthening the tunnel will require the runways to be raised by an equal amount to keep the runways even and level.

- Time Factor - A near-term time frame appears to be reasonable. This timing, however, does not include consideration for possible environmental litigation and a resulting delay in construction.

14) Redesign Terminal Facilities to Transport Passengers

- o Description - This strategy would reduce aircraft taxi and idle emissions by having aircraft parked in areas closer to the runway system. Passengers would be transported between the aircraft and the passenger terminal in ground vehicles that emit substantially less pollutants than aircraft. The "mobile lounges" used at the Dulles International Airport at Washington, D.C. are an example of such a system.

- o Emission and Fuel Savings - The runway and terminal configuration are not suitable for the construction of parking ramps to load and unload passengers at both LAX and SFO. Therefore, savings were not estimated.

- o Safety - No safety problems are involved.

- o Cost - This strategy will have a high impact on costs. The construction of a parking area and its related ramps and taxiways; the redesigning of the entire airport; the purchase of ground vehicles to move passengers to and from the terminal areas; and the hiring of additional staff to operate and maintain ground vehicles impose a heavy financial burden on the airport operator and the airlines.

- o Time Factor - Implementation of this strategy at Los Angeles International Airport and San Francisco International Airport would be in the long-term.

15) Control Departure Time

- o Description - This strategy would reduce idle emissions by minimizing the time spent in queue for departure. Procedures that can be used to control departure times and reduce delays include: (1) the use of gate holds until en route air traffic control clearance is obtained, and (2) the sequencing of departures in a way that minimizes the delay effects of differential departure speeds and wake turbulence interaction.

- Emission and Fuel Savings - Usually the controller exercises gate hold if delays start to exceed 15 minutes. Savings may be derived from the fact that controllers during peak departure periods usually build up a queue of about 10 aircraft. If this queue could be reduced to a length of 4 to 5 aircraft, enough to feed the runway system, then unnecessary idling of the remaining aircraft can be avoided. Therefore, a medium savings for departure idle emissions could result from this strategy. Also, a low fuel savings might be anticipated.

- Safety - No safety problems are anticipated.

- Cost - Impacts on costs are likely to be negligible. The additional workload imposed on controllers could probably be offset by savings in fuel.

- Time Factor - This strategy can be implemented in the immediate future. However, an agreement with the FAA Air Traffic Control would be necessary before implementation.

16) Alternative Deceleration Pattern

- Description - In many cases, arriving aircraft use reverse thrust to assist in deceleration, especially when landing in a direction away from the terminal (e.g., landing on Runway 24L at Los Angeles International Airport). This strategy would reduce engine emissions during landing by requiring that reverse thrust be used only for safety considerations.

- Emission and Fuel Savings - This strategy could provide a high decrease in NO_x landing emissions but, at the same time, increase landing HC and CO emissions a medium amount because engines will not be at the highest power setting. In addition, this strategy could create a low increase in HC, CO, and NO_x emissions due to longer arrival taxi distance and increase in departure idle/delay time while aircraft wait for other aircraft to clear the runway. Fuel savings would most likely be negligible.

- Safety - Because the pilot has the final authority in determining landing deceleration patterns, this strategy can only be implemented if the pilot determines that such action will not violate safety requirements. The safety decision, therefore, depends on aircraft performance characteristics, available runway length, weather conditions, and pilot techniques.

- Costs - Cost impacts are likely to be negligible.

- Time Factor - This strategy could be implemented immediately if pilot acceptance could be obtained.

17) Special General Aviation Procedures

- Description - Small general aviation aircraft (less than 12,500 pounds gross takeoff weight) typically require much shorter runway lengths for landings and takeoffs than larger and heavier aircraft. By permitting small aircraft to use special procedures such as long landings and intersection takeoffs, when appropriate, savings in taxi times and delays could be obtained. Normally, these procedures not only reduce the taxi and idle times for small aircraft but also benefit the larger aircraft, because any reduction in service times for small aircraft represents a corresponding reduction in idle time for other aircraft.

- Emission and Fuel Savings - Since this strategy is already in practice, savings were not estimated.

- Safety - No safety problems are anticipated.

- Costs - Cost impacts would be negligible.

- Time Factor - Already being implemented.

18) <u>Power Across Active Runways to Maintenance Area</u>

- Description - This strategy would be considered for San Francisco International Airport where aircraft must cross active Runways 28L and 28R to reach the maintenance area on the east side of the airfield. By requiring aircraft to use power rather than be towed across active runways, delays to other aircraft and corresponding aircraft emissions can be reduced.

- Emission and Fuel Savings - This operation mainly occurs in off-peak hours; therefore, no significant reduction in delays could be achieved. Furthermore, the frequency of occurrence is small when compared to that of other activities. The result would be a negligible savings.

- Safety - No safety problems would be anticipated.

- Cost - Costs due to the additional fuel consumption would be negligible because of the relatively infrequent occurrence.

- Time Factor - Could be implemented immediately.

19) <u>Runway Assignment</u>

- Description - This strategy would require that the assignment of runways for arrivals and departures to be based on the proximity of the runway to the aircraft parking position rather than on the orientation of the origin/destination airport. The objective would be to reduce the distance that aircraft must travel between the runway and gate area of the passenger terminal.

- Emission and Fuel Savings - A low savings in taxi time would result at LAX since the Sepulveda tunnel would limit wide-bodies being assigned to Runways 25 L/R. A negligible savings in taxi time would result at SFO because runway and gate choices are centralized and grouped together. Fuel savings would probably be negligible.

- Safety - No safety problems are anticipated.

- Cost - Cost impacts would be negligible.

- Time Factor - Reassignment of runways could be implemented in the immediate future subject to agreement by FAA Air Traffic Control.

A summary of the preliminary evaluation, according to each strategy and source category, is shown in Tables 5-3 and 5-4 for LAX and SFO, respectively. Changes are shown only for those parameters affected by a given strategy. Also, Tables 5-5 and 5-6 present the composite airfield emission decrease or increase (from all source categories), fuel savings, safety problems, cost impacts, and time frame for implementation. A very high cost would be over $100 million.

The composite airfield emission changes were determined as follows: First, the emissions estimated for each source category (refer to Tables 4-11 and 4-16) were factored by corresponding ranges of emission increase or decrease developed in Tables 5-3 and 5-4. These factors were based on the mean of each range. Second, the total amount of change resulting from all

TABLE 5-3. Range in emission change for each strategy implemented at LAX.

	Aircraft Operations							Ground Equipment Operations		
	Departure			Arrival						
Category/Strategy	Idle	Taxi	Takeoff	Idle	Taxi	Landing	APU	Ground Service Vehicle	Fuel Handling Storage	Aircraft Engine Maintenance
<u>Engine Shut-Down</u>										
Tow Aircraft	H↓	H↓	-	H↓	H↓	-	-	M↑	-	-
Underground Cable	H↓	H↓	-	H↓	H↓	-	-	N	-	-
Reduce # of Engines	M↓L↑	M↓L↑	-	M↓L↑	M↓L↑	-	-	-	-	-
<u>Volume & Type of Operations</u>										
Passenger Load Increase	L↓	L↓	L↓	L↓	L↓	L↓	L↓	L↓	L↓	L↓
Fleet Mix Control	M↓	M↓	M↓	M↓	M↓	M↓	M↓	L↓	-	-
Establish Quotas	N	-	-	N	-	-	-	-	-	-
<u>Gate Operating Practices</u>										
Terminal Ground Power	-	-	-	-	-	-	H↓	L↑	-	-
Delay Engine Start-Up	N	N	-	-	-	-	-	-	-	-
Modify Refueling Practices	-	-	-	-	-	-	-	-	L↓	-
<u>New Construction</u>										
Construct New Taxiways	N	-	-	N	-	-	-	-	-	-
Build More Gates	-	-	-	N	-	-	-	-	-	-
Build New Holding Areas	-	-	-	N	-	-	-	-	-	-
Strengthen Sepulveda Tunnel	N	L↓	-	N	L↓	-	-	-	-	-
<u>ACT Procedures</u>										
Control Departure Times	M↓	-	-	-	-	-	-	-	-	-
Alt. Deceleration Pattern	L↑	-	-	-	L↑	M↑L↓	-	-	-	-
Runway Assignment	-	L↓	-	-	L↓	-	-	-	-	-

<u>Notation:</u>

↓ Decrease or savings
↑ Increase
Single letter indicates a decrease or increase in <u>all</u> pollutants.
Double letter indicates a decrease or increase in first CO and HC, then second NO_x.

TABLE 5-4. Range in emission changes by source category at SFO.

Category/Strategy	Aircraft Operations							Ground Equipment Operations		
	Departure			Arrival						
	Idle	Taxi	Takeoff	Idle	Taxi	Landing	APU	Ground Service Vehicle	Fuel Handling Storage	Aircraft Engine Maintenance
<u>Engine Shut-Down</u>										
Tow Aircraft	H↓	H↓	-	-	-	-	-	L↑	-	-
Underground Cable	H↓	H↓	-	-	-	-	-	N	-	-
Reduce # of Engines	M↓L↑	M↓L↑	-	M↓L↑	M↓L↑	-	-	-	-	-
<u>Volume & Type of Operations</u>										
Passenger Load Increase	L↓	L↓	L↓	L↓	L↓	L↓	L↓	L↓	L↓	L↓
Fleet Mix Control	M↓	M↓	M↓	M↓	M↓	M↓	M↓	L↓	-	-
Establish Quotas	N	-	-	N	-	-	-	-	-	-
<u>Gate Operating Practices</u>										
Terminal Ground Power	-	-	-	-	-	-	H↓	L↑	-	-
Delay Engine Start-Up	N	N	-	-	-	-	-	-	-	-
Modify Refueling Practices	-	-	-	-	-	-	-	-	L↓	-
<u>New Construction</u>										
Construct New Taxiways	N	-	-	N	-	-	-	-	-	-
Build More Gates	-	-	-	N	-	-	-	-	-	-
Build New Holding Areas	-	-	-	N	-	-	-	-	-	-
<u>ACT Procedures</u>										
Control Departure Times	M↓	-	-	-	-	-	-	-	-	-
Alt. Deceleration Pattern	L↓	-	-	-	L↑	M↑H↓	-	-	-	-
Power to Maintenance	N	-	-	-	-	-	-	-	-	-
Runway Assignment	-	N	-	-	N	-	-	-	-	-

Notation: ↓ decrease or savings
↑ increase
single letter indicates a decrease or increase in <u>all</u> pollutants
double letter indicates a decrease in first CO and HC, then second NO_x.

TABLE 5-5. Summary of total airfield emission change, fuel savings, and associated impacts from preliminary strategy evaluation at LAX.

Category/Strategy	Emission Change		Fuel Savings	Safety	Costs	Time Factor
	CO & HC	NO_x				
Engine Shut-Down						
Tow Aircraft	M ↓	L ↓	M ↓	P	H ↑	LT
Underground Cable	M ↓	L ↓	M ↓	P	H ↑↑	LT
Reduce # of Engines	M ↓	N	N	S	N	I
Volume & Type of Operations						
Passenger Load Increase	L ↓	L ↓	L ↓	S	N	LT
Fleet Mix Control	M ↓	M ↓	L ↓	S	H ↑↑	LT
Establish Quotas	N	N	N	S	N	NT
Gate Operating Practices						
Terminal Ground Power	N	N	N	S	M ↑	NT
Delay Engine Start-Up	N	N	N	S	N	I
Modify Refueling Practices	N	N	N	S	M ↑	NT
New Construction						
Construct New Taxiways	N	N	N	S	H ↑	NT
Build More Gates	N	N	N	S	H ↑	NT
Build New Holding Areas	N	N	N	S	M ↑	NT
Strengthen Sepulveda Tunnel	L ↓	N	N	S	H ↑	NT
ATC Procedures						
Control Departure Times	L ↓	N	L ↓	S	N	I
Alt. Deceleration Patterns	L ↑	L ↓	N	P	N	I
Runway Assignment	L ↓	N	N	S	N	I

Notation: ↓ decrease or savings
↑ increase
↑↑ very high increase

TABLE 5-6. Summary of total airfield emission change, fuel savings, and associated impacts from preliminary strategy evaluation at SFO.

Category/Strategy	Emission Change		Fuel Savings	Safety	Costs	Time Factor
	CO & HC	NO_x				
<u>Engine Shut-Down</u>						
Tow Aircraft	M ↓	L ↓	L ↓	P	H ↑	LT
Underground Cable	M ↓	L ↓	L ↓	P	H ↑↑	LT
Reduce # of Engines	M ↓	N	N	S	N	I
<u>Volume & Type of Operations</u>						
Passenger Load Increase	L ↓	L ↓	L ↓	S	N	LT
Fleet Mix Control	M ↓	M ↓	L ↓	S	H ↑↑	LT
Establish Quotas	N	N	N	S	N	NT
<u>Gate Operating Practices</u>						
Terminal Ground Power	N	N	N	S	M ↑	NT
Delay Engine Start-Up	N	N	N	S	N	I
Modify Refueling Practices	N	N	N	S	M ↑	NT
<u>New Construction</u>						
Construct New Taxiways	N	N	N	S	H ↑	NT
Build More Gates	N	N	N	S	H ↑	NT
Build New Holding Areas	N	N	N	S	M ↑	NT
<u>ATC Procedures</u>						
Control Departure Times	L ↓	N	L ↓	S	N	I
Alt. Deceleration Patterns	N	L ↓	N	P	N	I
Power to Maintenance	N	N	N	S	N	I
Runway Assignment	N	N	N	S	N	I

Notation: ↓ decrease or savings
↑ increase
↑↑ very high increase

source categories was compared to the total airfield emissions. This percent total change was assigned to the appropriate range and presented as a H, M, L, or N. Since the parameters which affect CO and HC variations are closely related, separate changes were not presented for these two pollutants but, instead, are shown together.

A similar procedure was used to determine the composite airfield fuel savings which would result for each strategy implemented.

In order to examine the regulatory and jurisdictional conflicts between air pollution control agencies and agencies responsible for airfield operations that may arise from the implementation of a particular operational strategy, the responsibilities and authority of each agency involved must be addressed. The agencies concerned with airfield operations that could be involved with the implementation of a strategy are as follows:

- Federal Aviation Administration (FAA)
- Civil Aeronautics Board (CAB)
- California Public Utilities Commission (PUC)
- City of Los Angeles, Department of Airports
- City and County of San Francisco, Airports Commission

The FAA has major control and provides guidelines and regulation on airport operations which involve the movement of aircraft. It has authority to certify aircraft and aircraft engines as to their airworthiness. The FAA is also responsible for ensuring aviation safety. In addition, the FAA administers the Airport Development Aid Program which was established under the Airport and Airway Development Act of 1970.

The CAB has sole responsibility in the regulation of intrastate air carrier routes, level of service, and fares. It has the authority to institute court proceedings against regulation violations. The PUC has responsibility in regulating intrastate carrier routes, level of service, and fares in California.

Airport operators generally manage the facilities used by the airline carriers provided that FAA and CAB requirements are not violated. They can make recommendations to the FAA or CAB to change operating procedures so that local desires can be accommodated.

In addition to government agencies, the airline carriers and the pilots also have responsibilities in the operation of aircraft. Each airline has its own operations manual detailing procedures that their pilots will follow. These procedures may differ from airline to airline but they must meet FAA minimum requirements. The pilot has ultimate responsibility to ensure the safe operation of an aircraft. This responsibility is written into the Federal Aviation Regulations.

Strategies concerning engine shut-down and Air Traffic Control procedures would involve the FAA. Since aircraft towing, underground cable, and alternative deceleration pattern strategies appear to have safety problems, implementation of these strategies would cause regulation and jurisdictional conflicts at the federal government level. The strategy for reducing the number of engines has been recommended by the FAA in a recent advisory circular document as an approved procedure for saving fuel. Control of departure time and runway assignments would need the approval of the FAA Air Traffic Control.

Strategies associated with the volume of aircraft operations and the type of aircraft operating at a given airport would involve both the CAB and the PUC, since these strategies affect the level of service. However, in certain cases, quotas on the number of operations in a given time period can be established at an airport by the airport operator. It appears that passenger load increases and fleet mix control would precipitate regulatory and jurisdictional conflicts.

Strategies aimed at new construction would involve both the FAA and the airport operator. In special cases, such as strengthening the Sepulveda Tunnel, this could also involve the California Department of Transportation, to some degree, with regard to the safe design of the new construction. There appears to be no jurisdictional conflicts with these strategies.

Strategies associated with gate operating practices would involve the airlines and the airport operator. Although delay in engine start-up would require agreement on the part of each pilot, there appear to be no regulatory or jurisdictional conflicts resulting from strategy implementation.

5.3 Strategy Selection

Those strategies which appear to be most viable were selected for further analysis and examination. In order to be considered viable, a strategy must show at least a total emission reduction in the low range and must not have a very high cost impact (i.e., must cost less than $100 million). According to Tables 5-5 and 5-6, the following seven strategies meet the criteria for being viable:

1) Tow aircraft
2) Reduce number of engines
3) Passenger load increase
4) Strengthen Sepulveda Tunnel
5) Control departure time
6) Alternative deceleration pattern
7) Runway assignment

Based on this preliminary evaluation, the remaining 12 strategies were excluded from further analysis. However, if additional funding were available, these remaining strategies could be analyzed in detail in order to determine more quantitatively their viability.

6. EVALUATION OF SELECTED STRATEGIES

This chapter presents a quantitative evaluation of those strategies selected for further analysis and examination. The selected strategies are: tow aircraft; reduce number of engines; passenger load increase; control departure time; alternative deceleration patterns; runway assignment; and strengthen Sepulveda Tunnel. Emission and fuel savings were evaluated and presented in a separate section for each individual strategy. Cost impacts were evaluated and are presented for each strategy in the last section of this chapter. Other associated impacts (i.e., safety, jurisdiction and regulatory conflicts, and time frame for implementation) were previously presented in Chapter 5.

Without the reconstruction of Runways 25 L/R at LAX to handle wide-body aircraft, runway assignment would not be very effective in reducing emissions. Therefore, two strategies, runway assignment and strengthen Sepulveda Tunnel, were combined and evaluated jointly.

6.1 Tow Aircraft

This strategy proposes to tow arrival and departure aircraft at LAX and only departure aircraft at SFO. Due to the complexity of scheduling airfield-wide towing operations, simplifications have been made in order to perform this analysis within the scope of this study. The following are major assumptions used to estimate emissions and fuel savings:

- o This strategy will be 90 percent effective in reducing aircraft emissions in the taxi mode and the idle mode.

- o For the idle departure mode, two minutes (equivalent to push-back time) were assumed for engine warm-up. Emissions and fuel consumption were assumed to occur during this warm-up period.

- Only commercial-passenger and cargo aircraft would be towed. General aviation towing was not considered.

- Where taxi distances are small (less than 3500 feet), towing would not be implemented.

- Tow tractors which will most likely be owned by each individual airline company are assumed to make a round-trip (i.e., for arrival - a trip to the runway and tow back to the gate; for departure - tow to the runway and a return trip to the terminal area).

- Tow tractors will have an average speed of 15 miles per hour during a round-trip.

At LAX, towing will affect the following taxi routes:

Terminal Area	Arrival		Departure	
	24 L/R	25 L/R	24 L/R	25 L/R
North	X	X	X	X
Southwest	X		X	X
Southeast	X		X	X
Cargo	X		X	

Table 6-1 presents the emission estimates and fuel savings that may possibly be obtained after implementation of the strategy. At LAX and SFO, savings from aircraft were determined by applying a 90% factor to the commercial-passenger and cargo emissions and fuel use summed for those taxi routes affected. At SFO, all taxi routes for departure aircraft were affected by this strategy and the 90% factor was applied to commercial-passenger and cargo emissions and fuel use.

TABLE 6-1. Fuel and emission savings from tow aircraft strategy at LAX and SFO.

Category	LAX					SFO				
	Fuel	CO	HC	NO_x	TSP	Fuel	CO	HC	NO_x	TSP
<u>Savings From Aircraft</u>										
Taxi - Departure	-14.77	-2.40	-1.22	-0.13	-0.02	-8.74	-1.86	-1.06	-0.09	-0.01
Taxi - Arrival	-14.96	-3.05	-1.50	-0.13	-0.02	-	-	-	-	-
Idle - Departure	-3.56	-0.65	-0.33	-0.04	-0.01	-5.81	-1.23	-0.71	-0.06	-0.01
Idle - Arrival	-2.75	-0.56	-0.28	-0.02	0	-	-	-	-	-
Subtotal	-36.04	-6.66	-3.33	-0.32	-0.05	-14.55	-3.09	-1.77	-0.15	-0.02
<u>Increase From Tow Tractors</u>										
Tow Tractor Vehicles	+0.31	+0.29	+0.05	+0.03	Neg.	+0.06	+0.05	+0.01	Neg.	Neg.
Strategy Total	-35.73	-6.37	-3.28	-0.29	-0.05	-14.49	-3.04	-1.76	-0.15	-0.02

Note: minus (-) indicates a savings
plus (+) indicates an increase
Fuel - 10^3 gal/day
Emissions - tons/day

Tow tractor emissions and fuel use were estimated by determining the total number of hours the tractors operated. This was done using the number of commercial-passenger and cargo operations, and the time each tow tractor operated during a round trip. The number of tractor hours were then multiplied by the fuel consumption rate (2.4 gal/hour) to determine the total fuel used. Gasoline emission factors for tow tractors were used to estimate the emissions for each pollutant. Tractor emissions and fuel use account for an increase in ground service vehicle emissions and fuel consumption.

6.2 Reduce Number of Aircraft Engines

This strategy would require all commercial-passenger and cargo aircraft to shut down one engine when taxiing to or from the active runway. However, in order to maintain taxi speed, these aircraft must operate their remaining engines at a higher power setting. The determination of emission and fuel savings requires the re-calculation of idle and taxi baseline emissions for both departure and idle modes using fewer number of engines and different engine emissions rates.

Data for emission rate versus power setting were not available for each aircraft engine type. However, data were available from the Federal Aviation Administration (1974) for the JT3D (B-727 engine). It was assumed that this data would be representative of all engine types. Table 6-2 shows the percent change in emission rates and fuel consumption used to develop new factors according to the change in number of engines. Table 6-3 presents the new fuel use and emission factors calculated from the percent change in Table 6-2 and the baseline factors in Table 4-9.

These new factors were applied to the baseline aircraft operations and time in idle and taxi modes at both LAX and SFO. The new fuel and emission estimates were then subtracted from the baseline to determine the amount of savings or, in some cases, increase. Table 6-4 presents these savings and increases for LAX and SFO.

TABLE 6-2. Percent change in fuel and emission rates according to number of engines reduced.

Engine Reduction	Change in % of Full Power Setting	% Change in Rate/Engine				
		Fuel	CO	HC	NO_x	TSP
4 to 3	6 to 8	+25	-3	-10	+60	+37
3 to 2	6 to 9	+40	-5	-17	+76	+53
2 to 1	6 to 11	+71	-10	-34	+100	+86

Note: plus (+) indicates an increase over the baseline rate
minus (-) indicates a decrease over the baseline rate

TABLE 6-3. Fuel use and emission factors for with reduced number of operating engines.

Aircraft Type	No. of Engines	Fuel and Emission Rates (lbs/hr)[a]				
		Fuel	CO	HC	NO_x	TSP
<u>Commercial</u>						
B-747	3	2258	77.4	21.9	8.6	3.0
DC-10	2	1688	83.6	30.0	5.3	0
L-1011	2	2442	82.5	43.8	8.8	1.7
B-707	3	1266	136.6	112.1	3.5	.5
DC-8	3	1266	136.6	112.1	3.5	.5
B-727	2	1610	37.1	8.4	6.9	.6
B-737	1	1966	35.2	6.7	7.8	.7
DC-9	1	1966	35.2	6.7	7.8	.7

[a] for the idle/taxi mode

TABLE 6-4. Fuel and emission savings/increase from reduce number of aircraft engines strategy at LAX and SFO.

Mode	LAX					SFO				
	Fuel	CO	HC	NO_x	TSP	Fuel	CO	HC	NO_x	TSP
Idle										
Departure	-1.05	-0.95	-0.59	+0.02	0	-0.90	-0.85	-0.55	+0.02	0
Arrival	-0.39	-0.36	-0.22	0	+0.01	-0.46	-0.43	-0.27	+0.01	+0.01
Total	-1.44	-1.31	-0.81	+0.02	+0.01	-1.36	-1.28	-0.82	+0.03	+0.01
Taxi										
Departure	-1.14	-0.95	-0.56	+0.04	0	-0.68	-0.64	-0.40	+0.02	0
Arrival	-1.40	-1.24	-0.71	+0.05		-0.46	-0.43	-0.27	+0.01	+0.01
Total	-2.54	-2.19	-1.27	+0.09	0	-1.14	-1.07	-0.67	+0.03	+0.03
Strategy Total	-3.98	-3.50	-2.08	+0.11	+0.01	-2.50	-2.35	-1.49	+0.06	+0.02

Note: minus (-) indicates a savings
plus (+) indicates an increase

Fuel - 10^3 gal/day
Emissions - tons/day

6.3 Passenger Load Increase

Average load factor (i.e., percent seats occupied) for airlines under existing conditions is approximately 55% to 60%. It is to the airlines' advantage to increase passenger load since the marginal cost is much lower than the additional revenue. Therefore, the existing load factor reflects perhaps the upper limit of an airline's ability to attract passengers. Given a market demand, there is little more an airline can do to increase its load factor. Any discounts in air fare will soon be matched by other airlines and any reduction in scheduled operations will only be to the advantage of the competition. It is for these reasons that this study only investigated the effects of increasing average passenger load factor from between 55-60% to between 60-65%. This represents a reduction in aircraft operations of about 9%, if the aircraft fleet mix remains unchanged.

Savings for this strategy can only be obtained from commercial-passenger aircraft operations and associated ground support equipment. However, the savings is obtained in all modes due to the reduction in the total number of operations.

Baseline aircraft emissions were adjusted to reflect only the commercial-passenger portion for each mode. Savings were then estimated by applying the 9% factor. Table 6-5 presents the savings from aircraft emissions for LAX and SFO by mode.

Baseline ground equipment emissions were also adjusted to reflect those operations which would be reduced by increasing the passenger loading on commercial aircraft. Adjustments were made to exclude cargo, general aviation, and commuter related ground service emissions.

Table 6-6 shows the total savings from aircraft, ground service vehicles, fuel handling, and aircraft engine maintenance from implementation of this strategy.

TABLE 6-5. Fuel and emission savings from aircraft operations for passenger load increase strategy at LAX and SFO.

Mode	LAX					SFO				
	Fuel	CO	HC	NO_x	TSP	Fuel	CO	HC	NO_x	TSP
Idle										
Departure	1.15	0.23	0.14	0.01	0	1.06	0.22	0.13	0.01	0
Arrival	0.36	0.07	0.05	0	0	0.53	0.11	0.07	0.01	0
Total	1.51	0.30	0.19	0.01	0	1.59	0.33	0.20	0.02	0
Taxi										
Departure	1.20	0.23	0.13	0.01	0	0.79	0.17	0.10	0.01	0
Arrival	1.26	0.27	0.15	0.01	0	0.53	0.11	0.07	0.01	0
Total	2.46	0.50	0.28	0.02	0	1.32	0.28	0.17	0.02	0
Takeoff	3.78	0.01	0	0.31	0	2.64	0.01	0	0.19	0
Landing	1.23	0.05	0.03	0.07	0	0.87	0.04	0.02	0.05	0
Aircraft Total	8.98	0.86	0.50	0.41	0	6.42	0.66	0.39	0.28	0

Note: Fuel - 10^3 gal/day
Emissions - tons/day
All values are minus (-) or a savings

TABLE 6-6. Fuel and emission savings from all operations for passenger load increase strategy at LAX and SFO.

Category	LAX					SFO				
	Fuel	CO	HC	NO_x	TSP	Fuel	CO	HC	NO_x	TSP
Aircraft	8.98	0.86	0.50	0.41	0	6.42	0.66	0.39	0.28	0
Ground Service Vehicles	0.18	0.13	0.02	0.01	0	0.13	0.10	0.01	0.01	0
Fuel Handling	-	-	0.01	-	-	-	-	0.01	-	-
Aircraft Engine Maintenance	NA	0.11	0.14	0.01	NA	NA	0.08	0.03	0.04	NA
Strategy Total	9.16	1.10	0.67	0.43	0	6.55	0.84	0.44	0.33	0

Note: Fuel - 10^3 gal/day
Emissions - ton/day

NA - Not Available

All values are minus (-) or a savings

6.4 Control Departure Time

This strategy proposes to reduce aircraft emissions during the peak departure period by minimizing the time spent while idling in a queue. By implementing gate holds or sequencing aircraft departures, idling time could be reduced to about one-half of the current delay experienced during the peak departure period.

In order to determine the savings that could be obtained by implement ing this strategy, peak departure period emissions and fuel consumption were estimated for LAX and SFO. The savings would then be one-half of this amount.

Table 6-7 shows the diurnal distribution of departure operations at LAX and SFO for an average day. At LAX, there are two peak departure periods; they are from 8:00 a.m. to 10:00 a.m. and from 12:00 noon to 2:00 p.m. AT SFO, the peak departure period was from 12:00 noon to 3:00 p.m.

Since this strategy affects all aircraft departures experiencing delays, the following presents the mix of aircraft at LAX and SFO during the peak departure period.

	Number of Aircraft Departures	
Aircraft Type	LAX	SFO
B-747	11	3
DC-10	25	6
L-1011	11	4
B-707	21	9
DC-8	8	5
B-727	58	38
B-737	9	11
DC-9	13	3
Commuter	26	11
Business Jet	14	2
Propeller	22	12
Total	218	104

TABLE 6-7. Diurnal distribution of departure aircraft operations for an average day at LAX and SFO.

Time of Day	LAX		SFO	
	No. of Departures	% of Total	No. of Departures	% of Total
Mid - 1 am	18	2.5	12	2.5
1 am - 2 am	9	1.2	10	2.1
2 am - 3 am	3	0.4	2	0.4
3 am - 4 am	3	0.4	1	0.2
4 am - 5 am	6	0.8	0	0.0
5 am - 6 am	3	0.4	8	1.7
6 am - 7 am	16	2.2	6	1.3
7 am - 8 am	39	5.4	22	4.7
8 am - 9 am	54	7.5	35	7.6
9 am - 10 am	56	7.7	28	6.1
10 am - 11 am	40	5.5	24	5.3
11 am - Noon	40	5.5	23	4.9
Noon - 1 pm	64	8.8	38	8.2
1 pm - 2 pm	44	6.1	32	7.0
2 pm - 3 pm	32	4.4	34	7.4
3 pm - 4 pm	39	5.4	23	4.9
4 pm - 5 pm	48	6.6	23	4.9
5 pm - 6 pm	39	5.4	28	6.1
6 pm - 7 pm	35	4.8	20	4.4
7 pm - 8 pm	38	5.3	32	7.0
8 pm - 9 pm	23	3.2	24	5.3
9 pm - 10 pm	26	3.6	12	2.7
10 pm - 11 pm	36	5.0	19	4.2
11 pm - Mid	14	1.9	5	1.1
Daily Total	725	100.0	461	100.0

The time in idle mode for departures during the peak period was estimated to be about 0.5 minutes over the average day time at both LAX and SFO. Therefore, the peak period time in idle mode would be 3.5 minutes for LAX and 4.5 for SFO.

The peak period idle emissions and fuel consumption were determined using: number of departures shown above; baseline fuel use and emission factors presented in Chapter 4; and the departure idle mode times for the peak period. The following presents savings which would result from implementation of this strategy:

Fuel and Emission Savings per Peak Period

Airport	Fuel (10^3 gal)	CO (ton)	HC (ton)	NO_x (ton)	TSP (ton)
LAX	2.66	0.59	0.34	0.03	Neg.
SFO	1.63	0.34	0.20	0.02	Neg.

6.5 Alternative Deceleration Pattern

This strategy proposes that aircraft would not use engine reverse thrust during the landing operation, except when safety considerations (e.g., poor weather) were present. The effect of not using reverse thrust (which usually lasts about 10 seconds) would be to increase runway occupancy time by an average of one-half a minute.

The primary purpose of this strategy would be to reduce the NO_x emissions during landing since the aircraft engines would not be operating at the higher temperatures or higher power setting. However, trade-offs are important in considering implementation of strategy. These trade-offs include increased fuel use and emissions from additional taxi distances from the end of the runway to the terminal and from additional delays for departing aircraft due to the increase in runway occupancy time for arrivals.

The following discussion presents the methodology used to estimate the fuel consumption and emission savings from the landing mode. It was assumed that only commercial-passenger and cargo aircraft would be required to implement this strategy.

Recalling the equation shown in Chapter 4 which related the landing emission factor to the other modal emission factors, the elimination of reverse thrust would modify that equation to the following:

$$EF_L = 0.6\ EF_I + 0.4\ EF_A$$

where,	EF	=	Emission Factor (and Fuel Use Factor)
	L	=	Landing
	I	=	Idle
	A	=	Approach

The baseline landing fuel use and emission factors shown in Chapter 4 were modified for each aircraft type using the equation above to account for no reverse thrust. Essentially, the takeoff term of the equation was removed and included in the approach term. These new factors were then used to estimate fuel consumption and emissions with strategy implementation using the same number of aircraft operations at LAX and SFO. The resulting savings are as follows:

	Fuel Consumption	Emissions (tons/day)			
Airport	(10^3 gal/day)	CO	HC	NO_x	TSP
LAX	-9.82	+0.10	+0.01	-1.10	-0.01
SFO	-5.34	+0.06	+0.01	-0.51	0

The negative (-) sign indicates a savings and the plus (+) sign indicates an increase.

Although the fuel consumption and NO_x are reduced by this strategy, the CO and HC are increased since the engines emit more CO and HC at lower power settings.

The methodology for estimating the amount of increase from additional taxi distances and additional departure delay is discussed below.

The percent increase in taxi distance would be proportional to the percent increase in fuel consumption and emissions in the arrival taxi mode. At LAX, the additional taxi distance would be approximately 2600 and 3400 feet for Runways 24 L/R and 25 L/R, respectively. Since only commercial-passenger and cargo aircraft are effected, the following percent increase by terminal area were determined:

	Percent Increase in Arrival Taxi Distance	
Terminal Area	Runway 24 L/R	Runway 25 L/R
North	39	54
South-West	25	212
South-East	22	189
Cargo	17	-

AT SFO, the additional taxi distance would be approximately 3700 feet for Runways 28 L/R. This accounts for a 116 percent increase in average arrival taxi distance.

The increase in arrival taxi emissions were estimated using these percents and are as follows:

Airport	Fuel Consumption (10^3 gal/day)	Emissions (tons/day) CO	HC	NO_x	TSP
LAX	+7.47	+1.60	+0.93	+0.07	+0.01
SFO	+6.30	+1.23	+0.79	+0.06	+0.01

For LAX, Runways 24 L/R are used only for heavy wide-body arrivals. Therefore, the effects of longer arrival runway occupancy times are small because arrivals are infrequent. For Runways 25 L/R, under IFR conditions or VFR conditions with low demand, one runway can be used for arrivals and the other for departures. In this case, there will be no significant delays caused by the longer arrival runway occupancy times. During peak periods in VFR conditions, long arrival runway occupancy times could result in an increase of approximately 1.5 minutes per aircraft. VFR conditions occur about 74% of the time, and peak period represents four hours of the day. Furthermore, Runways 25 L/25 R have about 62% of the traffic. Therefore, the effect of this on delays over the average day is an increase of about 0.1 minute per aircraft.

For SFO, this strategy would not usually cause additional delays to departures. For example, departures on Runways 1 L/R only have to wait for arrivals on Runways 28 L/R to clear the runway intersection. Therefore, the additional arrival runway occupancy time does not affect departure operations. When Runways 28 L/R are used for both arrivals and departures, the controller can usually operate arrivals on one runway and departures on the other runway to avoid any conflict with departures. However, during peak periods in VFR conditions, it may be necessary to use both runways for arrivals (as well as departures) to accommodate the demand. Then during the peak period, average delays would increase by approximately one minute per aircraft. This runway use/weather condition occurs 24% of the time, and for about three hours of the day. Therefore, the effect on delays over the average day is an increase of about 0.1 minute per aircraft.

A 0.1-minute increase in departure delay accounts for a 3.3 percent and 2.5 percent increase in idle departure emissions for all aircraft at LAX and SFO, respectively. This increase would be as follows:

Airport	Fuel Consumption (10^3 gal/day)	Emissions (tons/day) CO	HC	NO_x	TSP
LAX	+0.49	+0.10	+0.06	0	0
SFO	+0.32	+0.07	+0.04	0	0

The total change in fuel consumption and emissions from implementation of this strategy is presented in Table 6-8 for LAX and SFO.

6.6 Runway Assignment and Strengthen Sepulveda Tunnel

This combined strategy proposes to assign departing aircraft to the runway that will minimize the taxi distance from the gate to the runway; and similarly, arriving aircraft would be assigned to the runway that is closest to their airline terminal location. This strategy is applicable only to LAX.

As an example, all aircraft located at the north terminal would be assigned to Runways 24 L/R for both arrivals and departures. Table 6-9 shows the distribution of aircraft operations for the baseline case and for this strategy.

The implementation of this strategy changes the distribution of operations as well as the aircraft mix on the runways. The number of operations on Runways 24 L/R is now 407 instead of 565 in the baseline, and that on Runways 25 L/R is now 1,038 compared to 880 in the baseline. Since the number of operations on Runway 24 L/R in the baseline case was already low in comparison with the capacity of the runways, reduction in operations

TABLE 6-8. Fuel and emissions savings/increase for alternative deceleration pattern strategy at LAX and SFO.

Category	LAX					SFO				
	Fuel	CO	HC	NO_x	TSP	Fuel	CO	HC	NO_x	TSP
Landing	-9.82	+0.10	+0.01	-1.10	-0.01	-5.24	+0.06	+0.01	-0.51	0
Taxi Arrival	+7.47	+1.60	+0.93	+0.07	+0.01	+6.30	+1.23	+0.79	+0.06	+0.01
Departure Delay	+0.49	+0.10	+0.06	0	0	+0.32	+0.07	+0.04	0	0
Total	-1.86	+1.80	+1.00	-1.03	0	+1.28	+1.36	+0.84	-0.45	+0.01

Note: minus (-) indicates a savings
plus (+) indicates an increase
Fuel - 10^3 gal/day
Emissions - tons/day

TABLE 6-9. Distribution of aircraft operations by terminal and runway for the baseline and runway assignment strategy at LAX.

Terminal Area	Baseline				Runway Assignment & Sepulveda Strategy			
	24 L/R		25 L/R		24 L/R		25 L/R	
	Arr.	Dep.	Arr.	Dep	Arr.	Dep.	Arr.	Dep.
North	27	75	50	19	77	94	0	0
South-West	23	110	116	33	0	143	139	0
South-East	41	173	174	53	0	0	215	226
Commuter	0	44	95	49	0	93	95	0
Cargo	36	36	0	0	0	0	36	36
Gen. Aviation	0	0	158	133	0	0	158	133
Total	127	438	593	287	77	330	643	395

for these runways would not decrease delays as much as the additional delays incurred on Runways 25 L/R due to operation increases on those runways. It was estimated that in VFR conditions the net increase in average aircraft delays due to this redistribution would be negligible. In IFR conditions, this additional delay was estimated to be about 0.5 minute per aircraft. Therefore, the effect on delays over the average day (considering both IFR and VFR conditions) would be an increase of about 0.2 minutes.

Another source of additional delays would be the cross-over of departure parths resulting from southbound departures from Runways 24 L/R and northbound departures from Runways 25 L/R. An analysis of the airfield operations showed that departure delays would not increase noticeably over the average day except during departure peak periods.

This new distribution of aircraft operations, the baseline fuel use and emission factors, the baseline time in taxi mode (distances from runway to terminal area would remain the same), and the additional delays on Runways 25 L/R were used to estimate fuel consumption and emissions that would be expected after strategy implementation. The savings are as follows:

Fuel (10^3 gal/day)	12.51
Emissions (ton/day)	
CO	2.22
HC	0.89
NO_x	0.13
TSP	0.03

6.7 Cost Impacts For Selected Strategies

This section presents approximate cost impacts for each of the selected strategies. Fuel cost were estimated using an average factor of 38 cents per gallon obtained from published statistics in the Penpon/IPC (1978).

Table 6-10 shows the resulting cost savings or increase for each strategy from fuel consumption changes. Generally, these costs indicate a substantial annual savings and should be considered as a beneficial impact. However, for tow aircraft, alternative deceleration patterns, and runway assignment plus Sepulveda Tunnel, these cost savings will be offset by other associated costs necessary for strategy implementation.

For tow aircraft, additional costs are necessary for: the acquisition of tractors, related equipment, and tractor fuel; increases in maintenance and operation staff, and flight crew costs; as well as possible purchase of additional aircraft to offset the impact of reduced aircraft utilization on schedule due to longer ground times. The estimation of such costs requires in itself a detailed study of the various factors involved in aircraft towing. This is considered to be out of the scope of the present study.

For the alternative deceleration pattern strategy, there are additional costs for increased airline crew time due to the longer taxi distances on arrival. Based on an analysis in a recent CAB (1978) published report, the estimated unit cost for a full airline crew is approximately $350 per block hour. The additional time required to land the aircraft, to taxi the longer distance, and to wait for departure will add to the total crew time. At LAX, the additional estimated cost would be approximately $7 million a year, and at SFO the additional cost would be approximately $3 million a year. Therefore, this strategy would have an adverse cost impact.

For runway assignment and Sepulveda Tunnel, the construction costs to strengthen Runways 25 L/R to handle wide-body aircraft were recently estimated by the Los Angeles Department of Airports (1977) to be about $16M. The cost savings attributed to the fuel savings would not significantly offset this additional cost. Therefore, this strategy would have an adverse cost impact.

The cost impacts for each strategy summarized according to beneficial (net savings) or adverse (expenditure) as follows:

TABLE 6-10. Cost impacts from fuel savings/increase for selected strategies at LAX and SFO.

Strategy	LAX Fuel (10^3 gal/day)	LAX Annual Cost ($M)	SFO Fuel (10^3 gal/day)	SFO Annual Cost ($M)
Tow Aircraft	-35.73	4.96	-14.49	2.00
Reduce No. of Engines	-3.98	0.55	-2.50	0.35
Passenger Load Increase	-9.16	1.27	-6.55	0.91
Control Departure Time	-2.66	0.37	-1.63	0.23
Alt. Deceleration Pattern	-1.86	0.26	(+1.28)*	(0.18)*
Runway Assign. & Sepulveda Tunnel	-12.51	1.74	0	0

Note: minus (-) indicates a savings
plus (+) indicates an increase
* no apparent savings

- Tow Aircraft -cannot be determined within the scope of this study.

- Reduce Number of Engines -beneficial cost impact.

- Passenger Load Increase -beneficial cost impact.

- Control Departure Time - beneficial cost impact.

- Alternative Deceleration Pattern - adverse cost impact.

- Runway Assignment and Sepulveda Tunnel - adverse cost impact.

7. CONCLUSIONS

This study identified nineteen (19) potential strategies for controlling air pollutant emissions from airfield operations at LAX and SFO. After a preliminary evaluation of these strategies, seven (7) were selected for further analysis and examination based on their viability. Although the remaining twelve (12) strategies were found to be either not effective in reducing emissions or effective but extremely costly, their viability should not completely be excluded. Instead, more detailed information should be developed for these strategies, in order to more quantitatively determine their effectiveness in reducing emissions.

Table 7-1 presents the amount of emission reductions and, in some cases, emission increases from implementation of the selected strategies at LAX and SFO. Also shown in Table 7-1 are the baseline emissions which were presented in Chapter 4.

The results of each strategy should be considered separately and not combined or added together. However, certain strategies could be implemented together but the total result may not be equal to the sum of the individual strategy result.

Future changes in fleet mix (aircraft types), new emission standards for gas turbine engines, and changes air traffic control systems could result in lower baseline estimates. Also, it is most likely that fuel costs will increase in the future. Therefore, the results of this study would not be applicable to future years, but reflect only current conditions.

Tables 7-2 and 7-3 present the results of the overall evaluation of the selected strategies at LAX and SFO, respectively. From these results, it appears that aircraft towing and reducing the number of engines would provide the most significant reduction in emissions (in the range of 20 to 40 percent) for CO and HC. These two strategies would not provide any substantial reduction in NO_x emissions. The towing strategy does appear to

TABLE 7-1. Summary of emission reduction or increase from implementation of the selected strategies at LAX and SFO.

Strategy	LAX Emissions (tons/day)				SFO Emission (tons/day)			
	CO	HC	NO_x	TSP	CO	HC	NO_x	TSP
Tow Aircraft	-6.37	-3.28	-.29	-.05	-3.04	-1.76	-.15	-.02
Reduce No. of Engines	-3.50	-2.08	+.11	+.01	-2.35	-1.49	+.06	+.02
Passenger Load Increase	-1.10	-.67	-.43	0	-.84	-.44	-.33	0
Control Departure Time	-.59	-.34	-.03	neg.	-.34	-.20	-.02	0
Alternative Deceleration Pattern	+1.80	+1.00	-1.03	0	+1.36	+0.84	-0.45	+0.01
Runway Assign. & Sepulveda Tunnel	-2.22	-0.89	-0.13	-0.03	-	-	-	-
Baseline Emissions	16.34	9.17	6.50	0.20	10.83	5.44	4.16	0.11

Note: Minus (-) indicates a savings
Plus (+) indicates an increase

TABLE 7-2. Summary of evaluation of selected strategies at LAX.

Selected Strategy	Percent Emission Change				Percent Fuel Use Change	Safety	Cost Impact	Imple. Time
	CO	HC	NO_x	TSP				
Tow Aircraft	-39	-36	-4	-25	-28	P	ND	LT
Reduce Number of Engines	-21	-23	+2	+5	-3	S	Beneficial	I
Passenger Load Increase	-7	-7	-7	0	-7	S	Beneficial	LT
Control Departure Time	-4	-4	0	0	-2	S	Beneficial	I
Alt. Deceleration Pattern	+11	+11	-16	0	-1	P	Beneficial	I
Runway Assign. & Sepulveda Tunnel	-14	-10	-2	-15	-10	S	Adverse	NT

<u>Notation:</u>

Minus (-) indicates savings
Plus (+) indicates increase
S – No apparent safety problem
P – Potential safety problem
ND – Not Determined
I – Immediate Future
NT – Near Term
LT – Long Term

TABLE 7-3. Summary of evaluation of selected strategies at SFO.

Selected Strategy	Percent Emission Change*				Percent Fuel Use Change	Safety	Cost Impact	Imple. Time
	CO	HC	NO_x	TSP				
Tow Aircraft	-26	-27	-4	-18	-18	P	ND	LT
Reduce Number of Engines	-20	-22	+1	+18	-3	S	Beneficial	I
Passenger Load Increase	-7	-7	-8	0	-8	S	Beneficial	LT
Control Departure Time	-3	-3	-1	0	-2	S	Beneficial	I
Alt. Deceleration Pattern	+12	+12	-11	+9	+2	P	Adverse	I

*Computed relative to the baseline ground level airfield emissions. The percentage change, when compared to total airport emissions, is roughly one-quarter to one-third of these values.

Notation: Minus (-) indicates savings
Plus (+) indicates increase
S – No apparent safety problem
P – Potential safety problem
ND – Not Determined
I – Immediate Future
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have a safety problem and most likely could not be implemented immediately. The cost impact of aircraft towing could not be determined within the scope of this study, but fuel savings appears to be significant. The cost of reducing the number of engines appears to have a beneficial impact due to the fuel savings and could be implemented in the immediate future. However, some airlines may already be shutting down one engine during taxi and idle. The extent of this practice at LAX and SFO was not determined in this study.

Passenger load increase and control departure time do not appear to provide any substantial emissions reductions or fuel savings (i.e., less than 10 percent). However, these strategies would not pose any safety problems and both have beneficial cost impacts. Control departure time could be implemented immediately, but passenger load increase would involve regulatory action from the CAB and PUC in California.

An alternative deceleration pattern appears to provide a small NO_x emissions reduction but would be offset by increases in CO, HC, and TSP emissions. Fuel savings appears to be negligible. Although this strategy does have an associated safety problem, it could be implemented immediately with the cooperation of the airlines and their pilots.

For LAX, runway reassignment and strengthening Sepulveda Tunnel appear to provide a substantial reduction in CO, HC, and TSP emissions, but only a small reduction in NO_x emissions. Also, a substantial fuel savings might be obtained. Although there are no safety problems associated with this strategy, it could not be implemented immediately due to the time requirement for new construction of the Sepulveda Tunnel. The cost impact appears to be adverse, again, due to the cost of construction.

From the results of this analysis of the selected strategies, reduce number of operating engines appears to be the most viable in terms of significant emission reduction, cost, safety, and implementation in the immediate future. However, aircraft towing could also be a viable candidate if the cost impacts do not appear to be adverse and the safety issues could be resolved.

The following is a list of technical areas which are suggested for further study:

- Prepare a more detailed analysis of the 12 strategies excluded from further analysis based on the preliminary evaluation.
- Prepare a more extensive baseline emission inventory of ground equipment operations and APU operations.
- Determine the total cost impacts of implementing the aircraft towing strategy.
- Determine the extent of the airlines already practicing the reduction of aircraft operating engines during idle and taxi.
- Develop data on emission and fuel use rates versus power settings for each aircraft engine type.

Completion of this additional research would provide the ARB with additional information for determining the effectiveness of airfield control strategies to reduce emissions at LAX and SFO.

Should the ARB decided to proceed with implementation of certain strategies, a potential area of assistance would be to help the ARB or local agency with developing guidelines for strategy implementation.